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Exploratory study on the body distribution of skin color, pigmentation and, degree of tan in Central European Caucasian Women

Alois W. Schmalwieser[1] · Sabine Götzinger[1] · Florian Schwabel[1]

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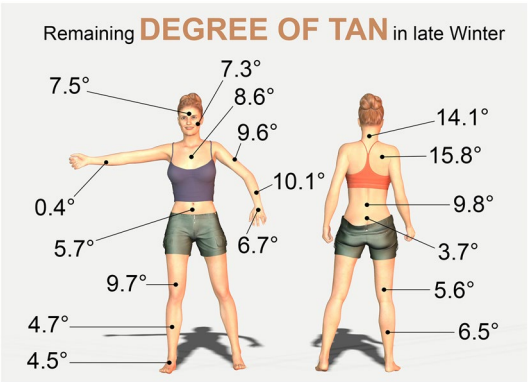
Abstract

It is well known that skin color varies by body site and with season. However, little quantitative data on the topography of skin color and pigmentation are available. Therefore, exploratory cutaneous colorimetric measurements in 20 in central European Caucasian women aged 20 to 60 years have been made at 18 body sites. Tri-stimulus $L^*a^*b^*$-values, hue, and chroma are considered to describe skin color. Based on the "Individual Typology Angle", the "Degree of Tan" was introduced to quantify the difference between constitutive and facultative pigmentation. Measurements were done in late winter and early summer to estimate potential changes by solar ultraviolet radiation. These measurements made evident that skin color obviously differs across the body in late winter. Even nearby body sites can be recognized as differently colored. A remaining degree of tan was found at permanent and intermittent exposed body sites. The remaining tan was not most pronounced at the permanently exposed sites but on the intermediate ones like the shoulder. In early summer, the degree of tan has most developed at the hands, arms, and instep, followed by the face. This study showed that besides basic differences between body sites in winter, accumulation, and degradation of tan also vary between body sites.

Graphical Abstract



1 Introduction

Human skin color originates from a variety of chromophores like melanin, hemoglobin, bilirubin, and carotene. Their concentrations and with that the contribution to perceived color differ not only by individual skin phenotype but also by anatomic body site. Besides pigmentation and blood flow, thickness of the skin also has a certain influence [1]. The amount and the distribution of chromophores within the skin can be altered by physiological processes as well as external physical agents. In the case of melanin, solar ultraviolet (UV) radiation may cause visible alterations [2, 3]. Therefore, the skin color of body sites changes with time, seasonally and across the lifespan (via changes in physiology, skin aging, etc.).

✉ Alois W. Schmalwieser
alois.schmalwieser@vetmeduni.ac.at

[1] Unit of Physiology and Biophysics, University of Veterinary Medicine, Veterinaerplatz 1, 1210 Vienna, Austria

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Skin color can be objectively determined by colorimetry. Cutaneous colorimetry has been an established method for decades. Measurements are done for manifold purposes, including estimation of environmental exposure, of physiological changes, controlling pharmacological interventions, and others [4]. One of the advantages of colorimetry is that measurements refer to the visual perception of the human eye. It therefore provides an objective measure for the perceived color [5, 6]. Besides that, colorimetry allows the determination of pigmentation by calculations from the distinct color measurements [7, 8].

As stated above, skin color and pigmentation are not homogeneous across the body and are not static. A dynamic topography of skin color and pigmentation results from this, which is caused by individual behavior [9] and environmental influences. However, the literature lacks information about skin color and pigmentation topography of the human body. Changes during the year are also only quantified for a restricted number of body sites.

In the case of pigmentation, one has to differentiate between facultative pigmentation and constitutive pigmentation. Constitutive skin pigmentation is the melanin content in the absence of solar UV radiation exposure and is genetically determined. It can be regarded as a baseline to quantify changes in pigmentation. Facultative pigmentation results from solar UV radiation exposure [10]. Constitutive pigmentation can be determined at body sites, which are not exposed to the sun. In large parts of the population, constitutive pigmentation can be measured at the buttock or at the medial aspect of the upper arm close to the armpit. For recruiting participants, the inner upper arm is most promising, since measurements at the buttock are often declined due to personal concerns induced by culture, gender, intimacy, and others. In nudists and excessive sun seekers, it is barely possible to determine constitutive pigmentation at all. The tan of a certain body site of a person can be determined by the difference between constitutive and facultative pigmentation. For pure skin color (chroma, hue, saturation, lightness), it is not yet clear whether there is a kind of constitutive skin color. However, skin color of the buttock and the inner upper arm is the lightest of the body [11].

Body sites may differ in color and pigmentation and may undergo apparent alterations during the year. Therefore, a proper baseline is of special importance. Such a baseline allows to determine the reaction of body sites to solar UV exposure, to compare the reaction of different body sites and to compare reaction of different study populations as the baseline level may influence the amount of reaction,

From above considerations, it becomes clear that colorimetric measurements have to be done and analyzed with care.

In Central Europe, pigmentation and thus skin color should be at its yearly minimum in late winter since it is not affected by the sun and should have decreased as much as possible. However, skin color and pigmentation may not return to the constitutive level in winter, but may accumulate at certain body sites [10, 12] when winter—respectively time without exposure—is not long enough for decline.

In this study, we quantified skin color and pigmentation of 20 adult women at 18 positions across the body in late winter to get the lowest possible level during the year. With this, a topography of skin color and pigmentation is established that enables inter-comparison between body sites and individuals. Topographic differences are analyzed in respect to the constitutive level, using the medial aspect of the inner upper arm close to the armpit. To show the influence of season, measurements were also done in late spring respectively early summer, when people are already exposed to solar UV radiation.

2 Materials and methods

2.1 Participants

Austrian Caucasian Women aged 20 to 60 years living in a sub-urban region near Vienna (48°N, 16°E, ca. 200 m a.s.l.) were invited to participate. Exclusion criteria were: visible irregularities of the skin at sites where color measurements were taken, present skin disease, present or previous skin cancer, skin photosensitivity disorders or intake of medicines that increase photosensitivity, use of solaria or sun holidays 5 months prior to February, regularly exposure to solar radiation or other UV radiation sources by occupation and nudists.

The study protocol was approved by an internal review board, and written informed consent to participate in the study was obtained from each volunteer. Besides age and Fitzpatrick skin phototype (FST) [13], no personal data have been used. Any other personal information like contact information of participants was kept confidential by one of the researchers.

The study population of this pilot study comprised 20 participants aged 20 to 60 years (average age of 39.7 years, Q1: 32, Q2: 38.5, Q3: 47). The volunteers ranged between FST (self-reported and checked for plausibility) I and III, with 15% type I, 70% type II, and 15% type III.

2.2 Body sites and time of skin color measurements

Measurements were done at 18 different body sites, which are depicted in Fig. 1. For baseline measurements, the medial aspect of the inner upper arm close to the armpit was selected and further referred to as inner upper arm. Three

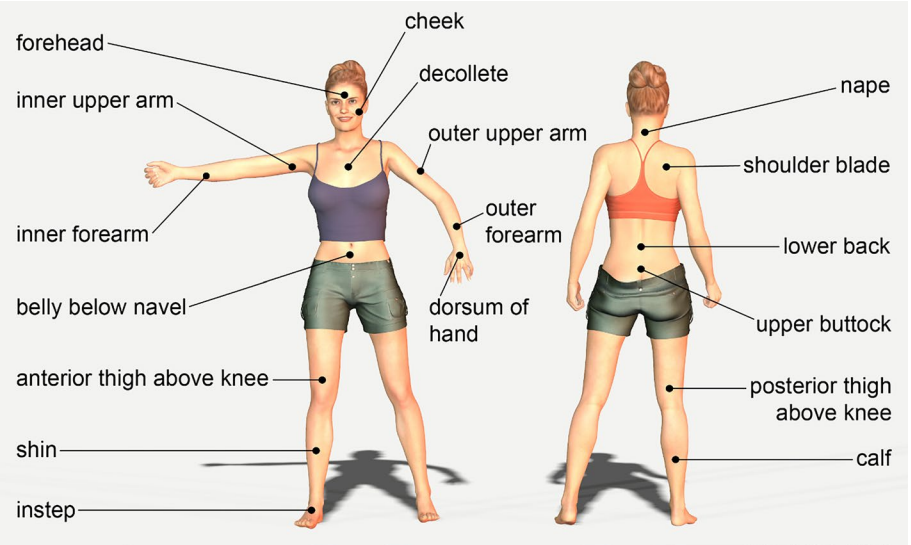

Fig. 1 Positions for skin color measurements

measurements were taken at each body part. The device was lifted between measurements. Visits to the volunteers took place in May and June as well as in February. February marks the end of the winter in Austria. Between November and the end of February, the solar environment is determined by low solar elevation (< 35°) and high cloud coverage, respectively a relative sun shine duration of 25%. On cloudless days, the erythemally effective irradiance is below 1.5 UV Index [14, 15] in this period [16, 17], respectively. Daily radiant exposure is below 7 SED (standard erythema dose according CIE) [18, 19]. Maximum air temperature during daylight hours is typically below 10 °C—with a dozen subzero days and around 50 frosty days [20]—and does not allow for the wearing of short-sleeved clothes. In May and June, the UV index can reach values between 5.5 (May) and 7 UV Index (June) at noon [16] and sun shine duration is around 50% [17]. Air temperature typically reaches 15 °C to 25 °C and enables wearing of short-sleeved clothes [33].

2.3 Tri-stimulus measurements of the skin and derivatives

Skin color measurements were made with a portable Chromameter (CR-300, Minolta, Osaka, Japan) [21]. This device is widely used in skin color measurements and its properties are well known [22, 23]. Instrument accuracy requires periodic calibration against its white plate standard and measurements have to be taken following the guidelines of Fullerton et al. [22]. Besides the tri-stimulus vales L^*, a^*, and b^*, their derivatives were used, whereas skin color is described by lightness L^*, the visual attribute of hue h° and saturation or chroma C* (for details see Appendix). To describe pigmentation, we used the individual typology angle ITA° (see Appendix for details).

Enhancement in pigmentation due to solar UV radiation exposure or differences to constitutive pigmentation is described by the difference between $ITA°_{con}$ of an unexposed site (constitutive pigmentation) and $ITA°_{fac}$ of the exposed site (facultative pigmentation). As tanning is the browning of the skin, especially by exposure to sun, this difference can be called the degree-of-tan TAN° and is expressed in units of degree:

$$TAN° - ITA°_{con} - ITA°_{fac} \quad (1)$$

TAN° was calculated separately for each body site using $ITA°_{con}$ gained from measurements at the inner upper arm (made at the same date).

2.4 Uncertainties of tri-stimulus measurements and derivatives

The Chromameter was periodically calibrated against its white plate standard but appeared very robust, and corrections were minor. The Minolta CR300 displays measurements of L^*, a^*, b^* with two decimal places, leading to 3 or 4 numbers in skin color measurements. Measurements without moving the device delivers values agree on the first decimal place and give the intrinsic accuracy/uncertainty.

The standard deviation of L^*, a^*, b^* of repeated measurements (interrupted by lifting and dropping, which avoids measurements of exactly the same location and takes into account—to a certain extent—the heterogeneity of skin color at the selected location) in the field was ± 0.31 in L^*, ± 0.31 in a^* and ± 0.23 in b^*, resulting in uncertainties in ΔE of ± 0.49, in h° of ± 1.2, in C^* of ± 0.37, and in ITA° of ± 1.1°.

2.5 Measures to distinguish differences in skin color and pigmentation

A difference in color ΔE of ± 1.0 can be recognized visually by an experienced trained observer [24], which corresponds—according Eq. 2 (Appendix)—to a difference of ± 1 if only 1 parameter differs, of ± 0.7 if two do, and ± 0.6 if all three do. According Eq. 5 (Appendix), a difference in $b^* = \pm 1$ results in a difference in ITA° of around ± 2.2, and a difference in $L^* = \pm 1$ leads to a difference in ITA° of around ± 1.5 (in inner upper arm skin of around $L^* = 68$, $b^* = 18$). For distinguishing two colors as different, a difference of 1.7 in hue h° and 0.8 in chroma C^* is necessary (see Appendix Eq. 3 and 4). These measures have between used to distinguish between different colors and degrees of pigmentation.

2.6 Statistical analyses

For analysis, arithmetic mean values ± standard deviation have been calculated. Correlation analysis and linear trend analysis were done using the data analysis and graphing software OriginPro 8.5 (OriginLab Corporation, Northampton, MA, USA) using Pearson's correlation coefficient and two-tailed t-test. A p-value < 0.05 was considered for significance.

3 Results

3.1 L*, a*, b*—values

Measurements made in February make evident obvious differences in skin color and pigmentation by body site. Mean values of L^*, a^*, and b^* for each body site are depicted in Fig. 2. In accordance with ΔE = ± 1 being recognized as a

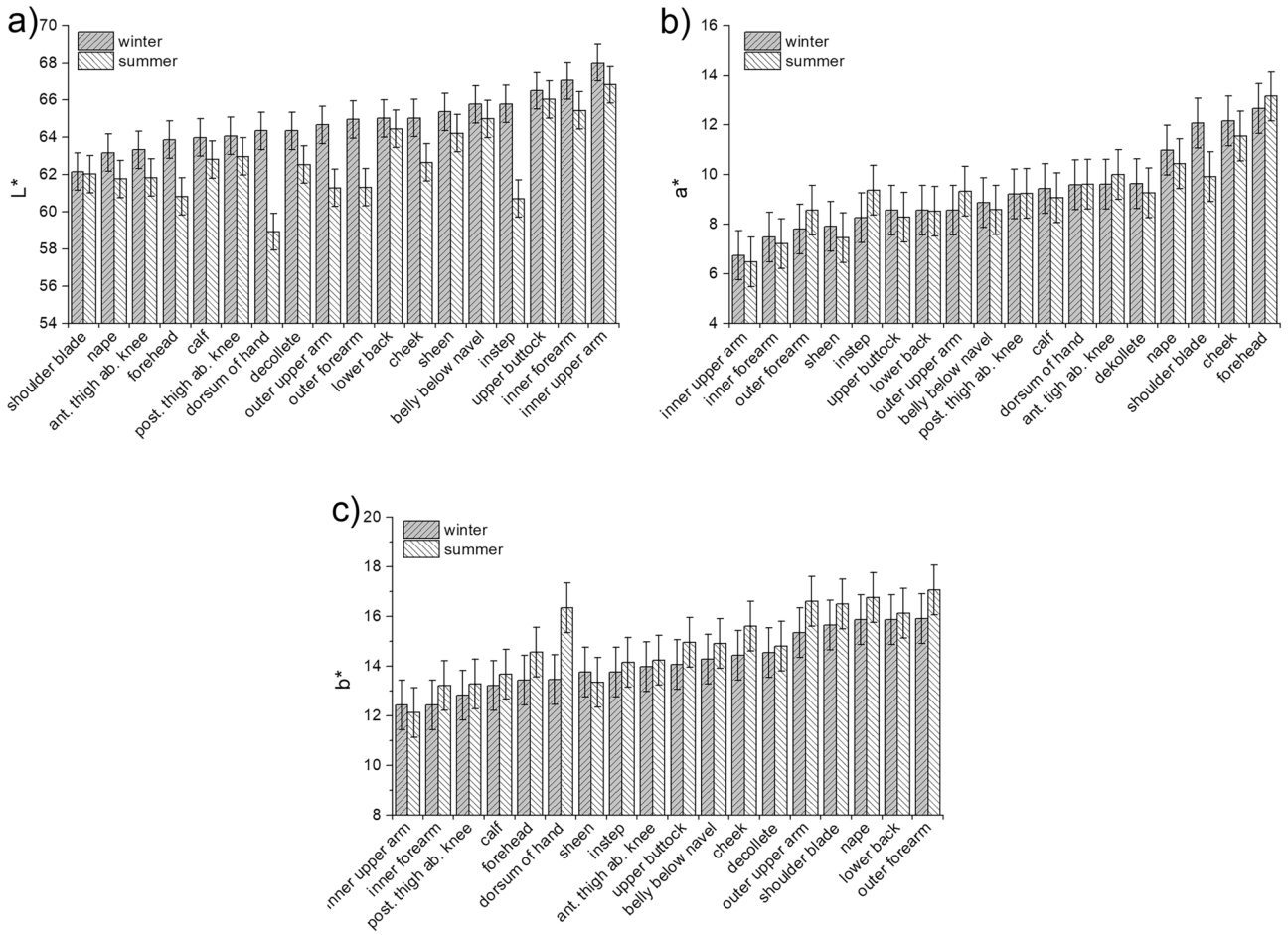

Fig. 2 Ranking of body parts by average L* (panel **a**), a* (panel **b**) and b* (panel **c**) in late winter (February) (gray hatched columns) of Austrian Caucasian women compared to mean values in early summer (late May and June) (hatched columns). Bars indicate the distance for distinguishing (visually) two colors as different

difference, differences in tri-stimuli L^*, a^*, and b^* of ± 1 can be recognized visually (indicated by the bars in Fig. 2). It can be seen (Fig. 2a) that the inner upper arm is the lightest on average and distinguishable from all others, followed by the inner forearm and upper buttock below belt line. The next 10 body sites only differ by less than 1.4. Anterior thigh, nape, and shoulder blade are clearly the darkest. The highest redness a^* (Fig. 2b)—on average—is found in the forehead, cheek, and shoulder blade. On the other hand, outer forearm, inner forearm and inner upper arm possess the lowest redness. Mean b^*-values (Fig. 2c) are the highest at the outer forearm, lower back, outer forearm, nape, and shoulder blade. These differ clearly from all others and are distinguishable by higher yellowness. On average, b^* is the lowest at the inner forearm and dorsum of the hand.

From Fig. 3, it can be seen that there is a clear and significant correlation ($c = -0.73$, $p < 0.001$) between L^* and a^* of body sites. Values cover the region form $L = 68/a^* = 6.7$ down to $L = 62/a^* = 12.6$. With that, body sites are partly quite different in redness. In contrast, there is no significant correlation between L^* and b^* ($c = -0.34$, $p > 0.21$) and also no significant correlation between a^* and b^* ($c = 0.21$, $p > 0.39$).

In May and June, mean values in L^* and b^* of body sites already differ from winter values (Fig. 2a, c) by undergoing a shift in the L^*–b^*-plane (Fig. 4) from higher L^* and lower b^* to lower L^* and higher b^*. Dorsum of the hand (18), instep (13), outer forearm (17) and outer upper arm (15) show the largest shifts. Sites at the leg changed minimally. On average, the shift of all body parts was -2.0 in L^* and +0.7 in b^*. Changes in a* are minor (see Fig. 2b) and do not differ perceivable from winter ($\Delta a^* < \pm 1$).

3.2 Skin color—chroma C*, Hue h° and L*

Mean values of hue h° and chroma C^* of body parts in winter are depicted in Fig. 5. The bars indicate the distances in

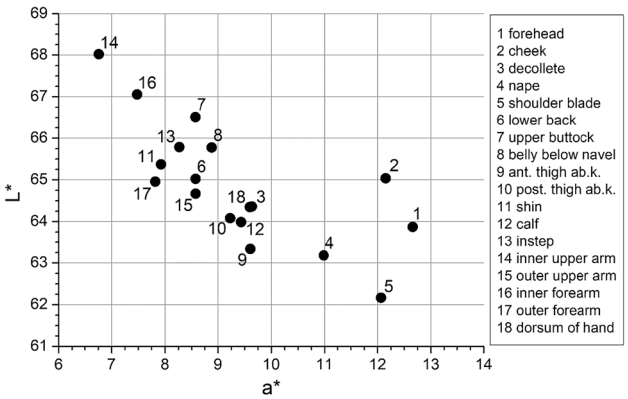

Fig. 3 Mean values of L* and a* for 18 body sites in Caucasian women in late winter

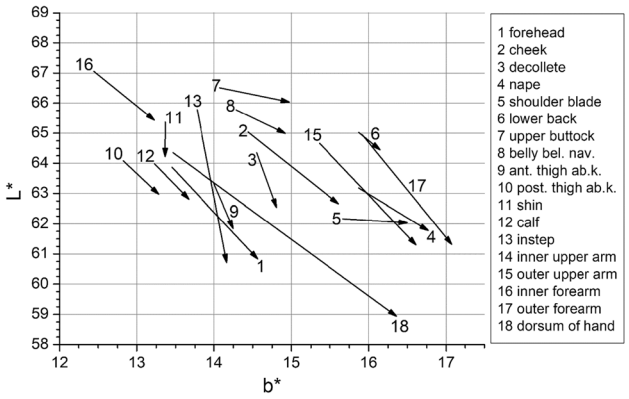

Fig. 4 Shift of body sites in the L^*-b^*-plane (tanning pathway) between winter (February) and early summer (May/June) for Caucasian women

chroma and hue which are necessary for recognizing two colors (indicated as filled circles) as different (at the same lightness L^*) by human eye. This distance is approximately 1.7 in hue h° and 0.8 in chroma C^*. It can be seen that forehead (1), cheek (2), shoulder blade (5) and nape (4) are located far from the others by clearly being of higher chroma, which denotes a brighter, respectively more saturated, color. They are also distant from each other in L*. On the other end, dullest (by lowest chroma) are the inner forearm (16) and inner upper arm (14). They are both the lightest on average (L* = 67 and 68). Lower back (6), outer upper arm (15), and outer forearm (17) show distinction by high chroma and large hue. Their L* value is almost the same. The other body parts are quite close to each other. Although forming a cluster, the color of certain sites like calf (12) and instep (13) can be distinguished.

In early summer, changes in color follow the changes of L^* and b^* (see Fig. 4), but are not very pronounced. Most

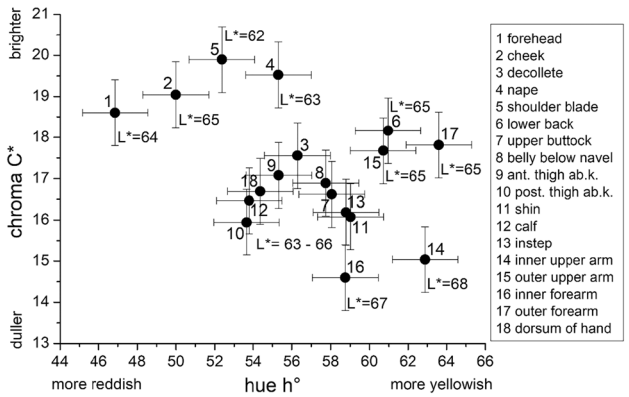

Fig. 5 Mean values of perceived skin color in chroma C° and hue h° for 18 body sites in Austrian Caucasian females in late winter. The bars indicate the necessary distance for distinguishability (at the same level of L^*) of two colors (indicated by filled circles)

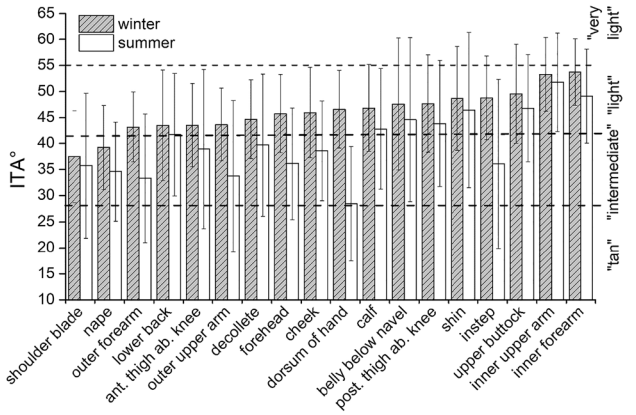

Fig. 6 Ranking of body sites by ITA° in winter from 20 women (hatched columns) compared to ITA° in early summer. Error bars depicted the standard deviation

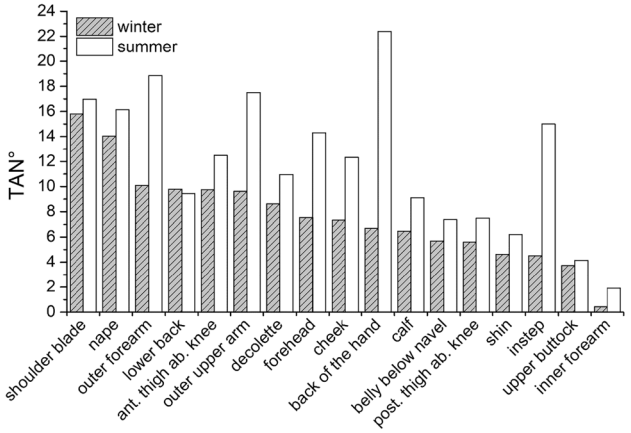

Fig. 7 Ranking of mean TAN° (degree of tan) at all body sites in late winter compared with values in early summer

obvious is the change at the dorsum of the hand, at the instep and at the outer arms. Some body parts have not shifted within $C^* < \pm 0.8$ and $h° < \pm 1.7$.

3.3 Pigmentation—ITA°

For pigmentation, ITA° in winter (hatched columns in Fig. 6) was found to be the lowest (highest pigmentation) on average at the shoulder and nape (<41°, graded as "intermediate"). Values between 41° and 45° were found for lower back, outer upper arm, outer forearm, anterior thigh (above knee), and décolleté. In contrast, the lowest pigmentation by values between 50° and 55° was found for the inner upper arm and inner forearm. For all other sites, ITA° ranges between 45° and 50°. All these sites can be graded as "light" (41–55°). The error bars in Fig. 6, depicting the standard deviation, indicate that the skin of some participants may also be categorized as "very light" (> 55°).

In early summer (empty columns in Fig. 6), ITA° has started to decrease across most of the body. Several body sites changed from "light" to "intermediate", but decrease is not correlated with winter-ITA°, so that the ranking (Fig. 6), done for winter values, is no longer valid. Correlation analysis was done for ITA° of the inner upper arm and FST, delivering a statistically significant correlation ($p < 0.05$).

3.4 Degree of tan—TAN°

The degree of tan TAN° in late winter provides information on accumulated pigmentation. From Fig. 7, it can be seen that winter-TAN° is the highest on the shoulder blade (TAN° = 16°) and on the nape (TAN° = 14), followed by outer forearm, outer upper arm, lower back, and lower anterior thigh (TAN°≈10°). These body parts receive intermittently high UV radiation exposure. Body parts exposed to the sun almost the entire year like décolleté, forehead, cheek, and dorsum of the hand have a lower TAN° (around 7° to 8°). Lower parts of the legs and the upper buttock accumulate the least pigmentation.

Additionally, we did not find any correlation between TAN° and age at any body site.

In early summer, TAN° of certain body site has already increased relative to winter, obvious at the outer forearm, outer upper arm, forehead, and cheek, but most at the instep and dorsum of the hand (from 7° to 23°). As winter measurements were made afterward, it becomes evident that fading of pigmentation can occur over a relatively wide range (> 16°), as seen at the dorsum of the hand.

4 Discussion and conclusion

In this paper, we quantified the distribution of skin color, pigmentation, and degree of tan along the body of Austrian Caucasian females. Although skin color measurements are used in many fields like dermatology (estimation of environmental exposure), physiology (physiological changes), pharmacy (controlling pharmacological interventions) or cosmetics [4], little focus has been put on the differences by body sites on a smaller scale in respect to a baseline in Caucasians previously.

Selection of body sites and analysis have to be done with care. In this study, we used the inner upper arm close to the armpit as baseline for constitutive pigmentation. Measurements made there, did not change from summer to winter, did not correlate with age, and are therefore appropriate for constitutive pigmentation. In sun seekers or user of solaria (excluded here), this could be different. Other positions at the inner upper arm (e.g., half-way between elbow and axillar) may be helpful in characterizing skin

aging [25] but are inappropriate as baseline for skin color and pigmentation as it shows seasonal variation [26]. For example, Bieliauskiene et al. [27] reported a change at the inner upper arm close the elbow with age, but this position is below the sleeve line when wearing short-sleeve garments. The inner forearm was also shown to be inappropriate as baseline [28]. Comparison between different studies is difficult or even impossible if no baseline (axilla or buttock) is available [25], because reaction to solar UVR may differ in study populations with different constitutive pigmentation (base line) and also the degree of reaction to solar UVR on different body parts cannot be estimated.

Our measurements showed that tri-stimulus values obviously differ by body site in winter, but even at nearby locations like forehead, cheek, and décolleté, or between the medial and lateral, as wells as proximal and distal aspect of the arms. Such differences have been reported mainly for the face in Caucasian females [29], but are rarely reported for other regions (e.g., aspects of arms) or between more distant anatomical sites. In Asian populations, much more data are available [30].

Mean values of L^* and a^* of body sites correlate to a certain extent. This can be explained by the fact that hemoglobin is of dark red color, so that a higher blood flow or higher density of vessels results in a darker red of the skin [31]. Mean L^* and b^* values of body sites may be related to each other, but do not show a close relation. Mean a^* and b^* do not correlate.

With that, different colors develop, and body sites differ in lightness (L^*), hue (h°), and saturation (C^*). Forehead, cheeks, nape, and décolleté possess the boldest colors, while inner forearm and inner upper arm possess the weakest colors. Responsible are differences in blood flow (L^*, a^*) by body site and differences in solar UVR exposure (L^*, b^*). In early summer, colors have mainly changed by reduced lightness and a slight increase in hue and saturation from a decrease in L^* and an increase in yellowness b^* (while redness has changed to a negligible extent).

The degree of tan TAN° relates facultative pigmentation to individual constitutive pigmentation. With that, enhancement of pigmentation by UV radiation can be measured objectively. In late winter, pigmentation and the degree of tan—although hardly affected by solar UV radiation at this time—also differ by body site. Interestingly, remaining pigmentation, respectively, remaining tan, is the highest at intermediate highly UV exposed body parts as the shoulder blade, nape and outer sites of the arms, but not at the permanently exposed sites like face and hands. Little is known about body distribution of melanin and about the effect of permanent and intermittent high UV exposure on production and depletion. At this point, one may speculate that sun adaption, by thickening of the horny layer,—as expected on permanently exposed parts—may deliver a protection factor of 4 [32], so that unadapted skin, like the shoulder blade after winter, receives a 4 times higher dose at the same UV irradiance/radiant exposure. This may cause a higher level of pigmentation that needs longer to fade and lasts into winter. In a population, which exposes the shoulders more often, an increase of TAN° with age should be found.

For this study, we have excluded persons with potentially high UV exposure like females with outdoor occupation, sun seekers and user of solaria. No correlation between tan and age could be found for any body site, which suggests that accumulated tan is influenced stronger by individual behavior than by age.

In early summer, tan has increased on several body sites. The back of the hand shows little tan in winter, but in early summer, it is the site with the highest tan. The instep has even lesser tan in winter, but has increased in a similar way during this time. Tan also increased at the outer upper and outer forearm. In Austria, instep and arms are typically exposed to the sun by the clothing at temperatures above 20 °C [33], which is in agreement with the temperatures in May and June in the region around Vienna. The shoulders and the back are highly exposed later at higher temperatures [33, 34], during summer and holiday season [35] (July to August), and receive high exposure at this time [36]. It can be assumed that TAN° increases further during summer.

As several studies made evident that measuring $L^*a^*b^*$ is an appropriate non-invasive method to estimate skin pigmentation in situ [37–39], our results clearly show that especially pigmentation (melanin) content, composition, and depletion differ by body site as well as the response of body sites to solar UV radiation does.

The limitations of our study are the relatively small number of participants, which are mainly of FST II. In Caucasian females with very light skin (FST I) or darker skin (FST IV), results could be different in several ways. Only one measurement was taken outside the winter period and UV radiation exposure of participants was not estimated, so that no quantitative conclusion on the time course (composition and depletion) could be made. Future research should therefore follow skin color and pigmentation with adequate time steps during a whole year, taking into account time spent outdoors and clothing.

Appendix: Tri-stimulus measurements of the skin and derivatives

Skin color is gained by a tri-stimulus analysis of a reflected xenon flash light providing a D65 illumination and is expressed as L^*, a^*, b^* tristimulus values [6] following the CIE color system [5, 6]. This is a 3-dimensional color space (see Fig. 2a) with a red–green axis a* ($a^* > 0$ is red),

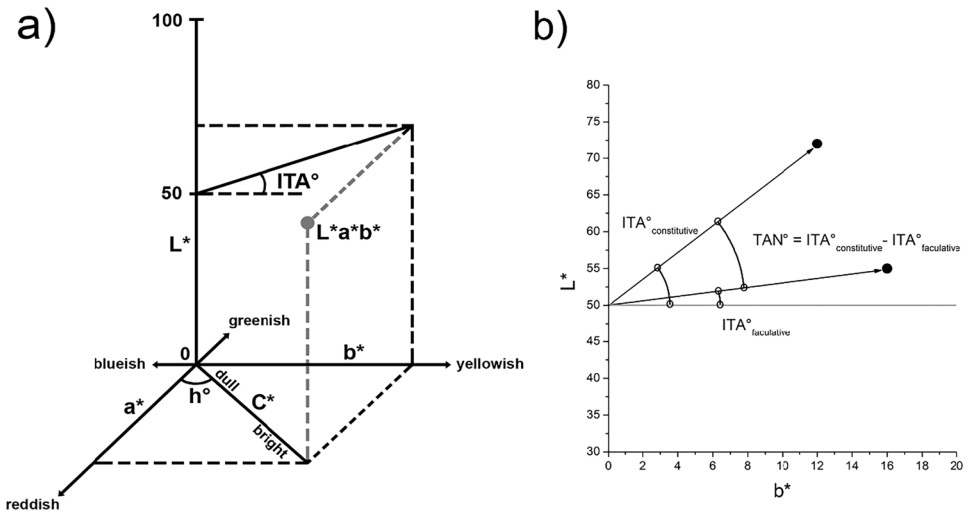

Fig. 8 Schematic representation of the $L^*a^*b^*$ color space and the derived quantities: Individual Typology Angle (ITA°), visual attribute of hue (hue angle, h°) and the perceived color attribute of saturation (chroma, C^*)

a yellow–blue axis b* ($b^* > 0$ is yellow) and a brightness/luminance axis L^*, ranging from black ($L^* = 0$) to white ($L^* = 100$). In skin color measurements, the values of a^* and b^* are positive. The Lab system has a close, linear relation to perception by the human eye.

The difference between two color stimuli ΔE is simply the distance between two $L^*a^*b^*$ measurements within in the color space:

$$\Delta E = \left((\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2\right)^{1/2} \quad (2)$$

whereas ΔL* is the difference of two measurements in L*, Δa* in a* and Δb* in b*.

This measure ΔE can be used to quantify the color difference between two body sites, the color difference between two points in time, as well as to estimate the measurement accuracy with respect to agreement of repeated measurements. According to Morkrzycki and Tatol [24]: $0 < \Delta E < 1$: observer does not notice the difference, $1 < \Delta E < 2$: only experienced observer can notice the difference, $2 < \Delta E < 3.5$: unexperienced observer also notices the difference, $3.5 < \Delta E < 5$: clear difference in color is noticed, $5 < \Delta E$: observer notices two different colors.

Therefore, ΔE should be ≤ 1.0 because this difference can be recognized visually.

From a^* and b^*, the hue angle h° can be calculated, which is a psychometric correlate of the visual attribute of hue:

$$\mathrm{h}^\circ = \arctan(b^*/a^*) * 180/pi \quad (3)$$

An increase of a* (e.g., by erythema) lowers h°, while an increase of b* enlarges this angle (see Fig. 2a). Vice versa, $h^\circ = 0$ corresponds to red and $\mathrm{h}^\circ = 90^\circ$ to yellow. In this color space, red and yellow induce brown via orange.

The visually perceived color attribute of saturation, chroma C^*, can be calculated as:

$$C^* = \left(a^{*2} + \mathrm{b}^{*2}\right)^{1/2} \quad (4)$$

C^* corresponds to the distance of a^* and b^* in the a^*–b^*plane from the L^*-axis (see Fig. 8a) and the angle between C^* and the a^*–axis is described by h° (see above). The brighter, respectively the more saturated a color is, the higher is its C^* and vice versa: a lower C^* represents a duller color.

In respect to skin color and pigmentation, Chardon et al. [7] have developed a vector representation of UV radiation-induced redness (e.g., erythema) and tanning respectively of the tanning pathway (as shifts in the L^*–b^*-plane). Pigmentation can be described in the L*–b* plane by the so-called "Individual Typology Angle" (ITA°) (see Fig. 2a):

$$\mathrm{ITA}^\circ = ((L^* - 50)/b^*) * 180/\pi \quad (5)$$

For ITA° measured at a site with constitutive pigmentation (ITA°_{con}), an $\mathrm{ITA}^\circ_{con} > 55^\circ$ denotes very-light skin, $55^\circ \geq \mathrm{ITA}^\circ_{con} > 41^\circ$ denotes light skin, $41^\circ \geq \mathrm{ITA}^\circ_{con} > 28^\circ$ denotes intermediate, $28^\circ \geq \mathrm{ITA}^\circ_{con} > 10^\circ$ denotes tan or matt, and $\geq 10^\circ$ $\mathrm{ITA}^\circ_{con} < -30^\circ$ denotes brown and $\mathrm{ITA}^\circ_{con} \leq -30^\circ$ denotes dark skin [7, 40].

A decrease in L* (darkening) or an increase in b^* (yellowing) leads both to a decrease in ITA°, denoting a decrease of ITA° with increasing pigmentation.

Enhancement in pigmentation due to solar UV radiation exposure or differences to constitutive pigmentation is described by the degree of tan TAN° (difference between ITA°_{con} of an unexposed site (constitutive pigmentation) and ITA°_{fac} of the exposed site (facultative pigmentation)). The degree of tan TAN° as defined is therefore a well-defined angle within the L°–b^*-plane (see Fig. 8 b).

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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