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Perceived Age in Patients Exposed to Distinct UV Indexes: A Systematic Review

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Abstract

Photodamage is caused by chronic sun exposure and ultraviolet radiation and presents as wrinkles, sagging, and pigmented spots. An increase in the ultraviolet index can increase a person's perceived age by worsening skin photodamage. However, since the ultraviolet index varies considerably between geographical regions, perceived age might vary substantially among them. This review aims to describe the differences in chronological and perceived age in regions of the world with different ultraviolet indexes. A literature search of three databases was conducted for studies analyzing perceived age and its relationship to sun exposure. Ultraviolet indexes from the included studies were retrieved from the National Weather Service and the Tropospheric Emission Monitoring Internet Service. Out of 104 studies, seven fulfilled the inclusion criteria. Overall, 3,352 patients were evaluated for perceived age. All studies found that patients with the highest daily sun exposures had the highest perceived ages for their chronological age ($p < 0.05$). People with high sun exposure behaviors living in regions with high ultraviolet indexes will look significantly older than same-aged peers living in lower ultraviolet index regions.

Keywords
- ► perceived age
- ► photoaging
- ► photodamage
- ► ultraviolet light
- ► geographical location

Introduction

In industrialized countries, the demographic curve has been continuously shifting toward an older population. Predictions show that by 2050 the average American will have a life expectancy at birth of around 85 years for men and 90 years for women.[1] In a society where beauty is held in high regard, looking young for one's age will undoubtedly continue to gain popularity. Although age-related facial changes depend on several factors, sun exposure is one of the most important ones. This statement is supported by the fact that comparisons between sun-protected and sun-exposed skin areas of the same individual have different histological findings associated with skin aging.[2] Damage to the skin due to chronic sun exposure is caused by ultraviolet (UV) radiation, and the skin changes that come with it are known as *photodamage*. Facial features that can be found in patients with photodamage include wrinkles, sagging, and pigmented spots, among others.[3,4] Current skin aging assessment uses scales that evaluate the isolated characteristics of photodamage to provide an overall score of skin status, correlating linearly with chronological age.[4,5]

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Table 1 Inclusion and exclusion criteria

Inclusion criteria	1. Studies correlated sun exposure to perceived age 2. Studies provided the mean perceived age of the patient groups or the difference between chronological and perceived age 3. Studies were in English
Exclusion criteria	1. Studies did not provide the perceived age as an outcome of interest 2. Studies did not provide a correlation between perceived age and sun exposure 3. Studies were reviews

According to the World Health Organization, the UV index serves as a measure of UV radiation, reflecting the amount of radiation that reaches the Earth.[6] Since many factors can modify this index, different geographical regions of the world have considerable differences in the amount of radiation received. The sun's height in the sky, latitude, cloudiness, altitude, ozone layer thickness, and the ground reflection all influence the amount of UV radiation that reaches our skin and eyes.[7] Since UV radiation is one of the most critical factors generating skin photodamage, perceived age by the ordinary observer might vary substantially in different populations and regions. In light of this, this review aims to analyze the relationship between perceived age and UV indexes of different regions of the world. We hypothesize that patients living in regions with higher UV indexes will be perceived as older than same-aged peers living in regions with lower UV indexes.

Methods

Studies were identified by searching PubMed, CINAHL, and Embase from inception to June 11, 2020. The following terms were used in combination: "solar exposure," "UV light," "ultraviolet light," "sun exposure," "skin aging," "photoaging," "solar aging of skin," "photodamage," "skin wrinkling," "hyperpigmentation," "sun-induced aging," "actinic damage," "perceived apparent age," "perceived age," or "chronological age." The search strategy can be found as **Supplementary Material** (available in the online version only).

The inclusion and exclusion criteria can be found in ►**Table 1**. No specific publication status was considered. The study selection process, along with the reasons for exclusion, is detailed in ►**Fig. 1**. This study was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Guidelines. Eligibility

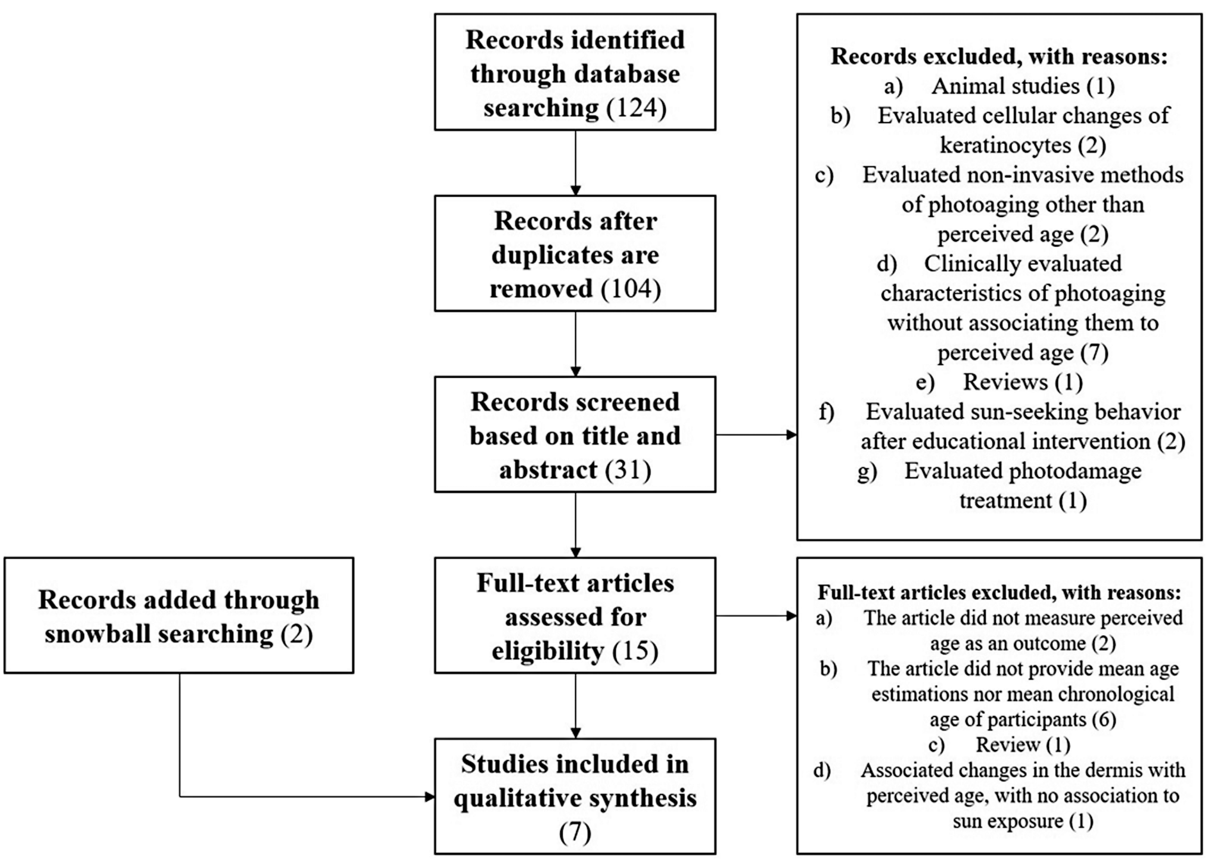

Fig. 1 Study selection flowchart. Summary of the study selection process using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart.

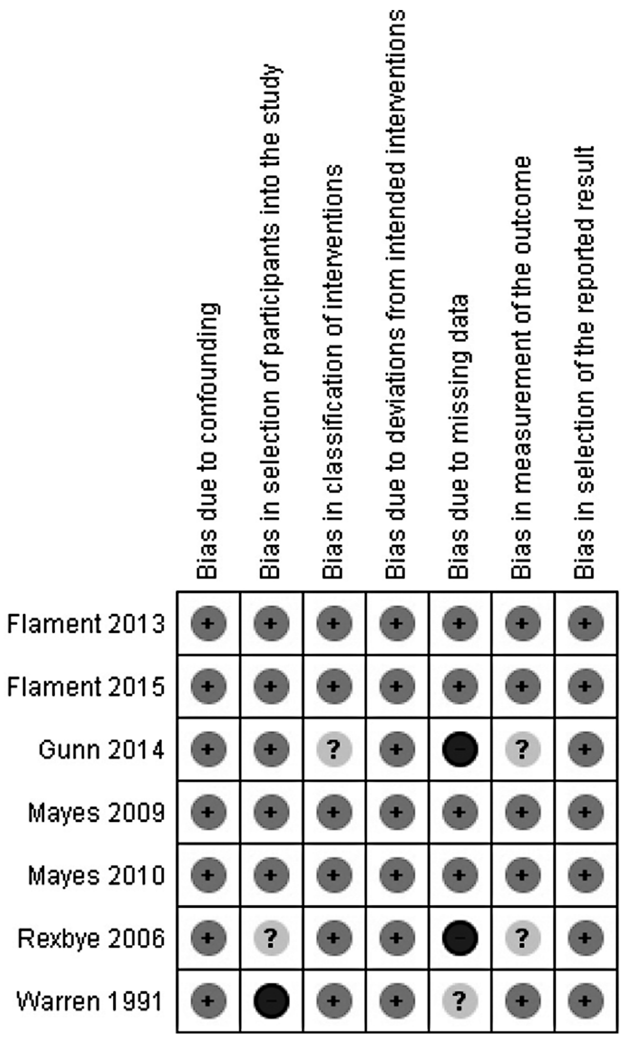

Fig. 2 Risk of bias summary. The figure shows each article's risk of bias in the different components of the analysis. Dark gray stands for high risk of bias, light gray stands for unclear risk of bias, and medium gray stands for low risk of bias. The risk of bias summary was created using RevMan 5.3.

assessment and data extraction were performed by one reviewer (FRA), starting with the title of the studies and followed by abstract and full-text evaluations. The risk of bias of included studies was assessed using the ROBINS-I tool of the Cochrane Library for nonrandomized studies.[8] A summary and a graph were created using RevMan 5.3 (Cochrane Collaboration), which allows for bias stratification in several domains (►**Figs. 2** and **3**). UV indexes were obtained from the National Weather Service's Climate Prediction Center and the Tropospheric Emission Monitoring Internet Service of the European Space Agency for the US and for the rest of the regions, respectively. Data obtained from both sources were used to obtain a mean UV index of the year the studies were published.

Due to missing individual data, and because both measurements belong to the same sample, the difference between perceived and chronological age cannot be calculated. The perceived and chronological ages, along with the region's mean UV index, will be reported in the following paragraphs. Relevant associations between perceived age and high sun exposure will be highlighted and discussed.

Results

The database searches identified 124 studies, of which five fulfilled the inclusion criteria. Two more studies that fulfilled the inclusion criteria were later added through searching of the included studies' references, for a total of seven studies. These studies are summarized in ►**Table 2**. All seven studies were cross-sectional and evaluated a total of 3,352 patients for perceived age. Of note, Mayes et al[9,10] cohort was counted only once. Four studies evaluated White patients, while three studies evaluated Asian patients. Sun exposure was evaluated differently in all studies. All studies provided photographs of the patients to the evaluators; no evaluator assessed patients in person. Photograph methods differed among studies. All studies found a statistically significant

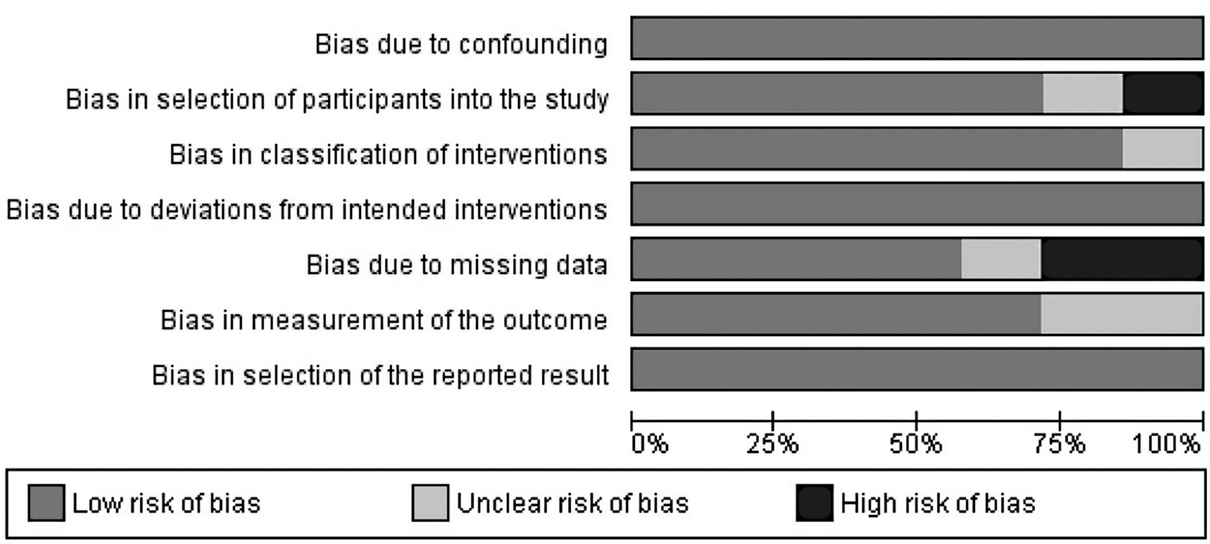

Fig. 3 Risk of bias graph. The figure shows the risk of bias across studies. Dark gray stands for high risk of bias, light gray stands for unclear risk of bias, and medium gray stands for low risk of bias. The risk of bias graphs was created using RevMan 5.3.

Table 2 Summary of included studies

Author, year, and country	Number of patients	Patient place of residency	Race	Sun exposure evaluation	Mean chronological ages	Mean perceived ages	Evaluation method	Results
Warren et al[11] 1991, United States	41 women	Tucson, Arizona	White	High exposure groups had ≥ 12 hours of sun exposure, low exposure groups had ≤ 2 hours of sun exposure	Young group with high exposure (27.1 ± 0.6); old group with high exposure (47.6 ± 0.4)	Young group with high exposure (30.8 ± 1.3); old group with high exposure (58.2 ± 1.1)	Photography	Perceived age was significantly higher in all groups. However, within the older group, women with high sun exposure showed a significantly increased perceived age compared to those with lower sun exposure ($p < 0.05$)
Rexbye et al[12] 2006, Denmark	1,826 twins (840 men and 986 women)	Denmark	White	Indoor work vs partly indoor work	Men (77 ± 5.6) and women (78.4 ± 6)	Men (77.6 ± 3.8) and women (78.0 ± 4.6)	Photography	For men, greater sun exposure significantly increased perceived age ($p < 0.02$). Sun exposure shows a tendency to increase perceived age in women
Mayes et al[9] 2010, United Kingdom	239 women (14 patients were analyzed)	Shanghai, China	Asian	Overall photodamage was assessed on a 0-9 scale (perceived older group had a score of 7.41 ± 1.02)	Perceived older group (61.13 ± 1.72)	Perceived older group (66.87 ± 4.38)	Photography	Photodamage was correlated with perceived age ($r = 0.960$, $p < 0.001$)
Mayes et al[10] 2010, United Kingdom	239 women	Shanghai, China	Asian	Occupational sun exposure (work/worked inside, equal time inside and outside, work/worked outside) and current sun exposure (not much time in sun, sometime in the sun, a lot of time in the sun)	N/A	N/A	Photography	Patients with higher sun exposure looked older than those with low exposure ($p = 0.011$). Patients who work/worked outside looked significantly older than those who work/worked inside ($p < 0.001$)
Flament et al[13] 2013, France	298 women	Montpellier, France	White	SS and SP groups were created based on sun behavior evaluation and the SBSH	N/A	N/A	Photography	The differences between perceived and chronological age were different between sun exposure groups except in those older than 70 ($p < 0.05$)

Table 2 (*Continued*)

Author, year, and country	Number of patients	Patient place of residency	Race	Sun exposure evaluation	Mean chronological ages	Mean perceived ages	Evaluation method	Results
Flament et al[14] 2015, France	301 women	Guangzhou, China	Asian	NE and SP groups were created based on sun behavior evaluation	N/A	N/A	Photography	The differences between perceived and chronological age were different between sun exposure groups for the age groups of 20-29, 40-49, and 60-69 ($p < 0.05$)
Gunn et al[15] 2015, United Kingdom	329 Dutch women, 318 Dutch men	Denmark	White	Survey: "how often have you been in the sun in the summer?", and "what do you do when sunbathing?"	Women (61.6 ± 6.0), men (63.8 ± 5.8)	Women (63 ± 0.8), men (60.3 ± 0.63)	Photography	Increased sun exposure and sunbed use increased perceived age in men and women ($p < 0.05$)

Abbreviations: NE, normal exposure; N/A, not applicable; SBSH, sun behavior score history; SP, sun-phobic; SS, sun-seeking.

Table 3 Coordinates, differences between chronological and perceived age, and UV index per region

Region (coordinates)	Surrogate region (coordinates)	UV index
Tucson, Arizona (32.2167°, −110.9167°)	Phoenix, Arizona (33.4333°, −112.0667°)	6.67
Copenhagen, Denmark (55.7167°, 12.5667°)	N/A	2.69
Shanghai, China (31.1667°, 121.4167°)	Tianjin, China (39.3333°, 117.3333°)	5.30
Montpellier, France (43.6667°, 3.8333°)	Haute Provence, France (44.1667, 6.0000)	4.45
Guangzhou (Canton), China (23.1167°, 113.2500°)	Hong Kong, China (22.2500°, 114.1667°)	2.77

Abbreviation: UV, ultraviolet.

correlation between perceived age and sun exposure in at least one of the evaluated groups.

The following paragraphs describe the most relevant information regarding each study while providing the mean UV index for the year in which the study was published. If the mean UV index for the specific location could not be retrieved, the place with the closest latitude and longitude for which information was available was used as a surrogate. Information regarding latitude, longitude, and UV index are summarized in ►**Table 3**.

Warren et al[11] evaluated a group of 41 White women living in Tucson, Arizona, who were divided into two groups, one with high sun exposure (≥12 hours/week) and one with low sun exposure (≤2 hours/week). The authors further separated the groups in ages (young adults from 25 to 31 years old and middle-aged adults from 45 to 51 years old), yielding four groups (young with high exposure, young with low exposure, old with high exposure, old with low exposure). The authors found a significantly increased ($p < 0.01$) perceived age in the older group with high sun exposure (58.2 ± 1.1) when compared to patients of the same age and low sun exposure (53.7 ± 1.3). The mean chronological age of the older group with high sun exposure was 47.6 ± 0.4. The mean UV index near Tucson, Arizona, is 6.67.

Rexbye et al[12] used the Longitudinal Study of Aging Danish Twins database to determine environmental factors modifying age perception. Patients were classified into two groups (indoor work, partly outdoor work) based on their profession's sun exposure levels. By performing multivariate regression analysis, the authors found that sun exposure significantly increased perceived age ($p = 0.02$) in men, with a tendency for statistical significance in women. The chronological age of men was 77 ± 5.6, while their perceived age was 77.6 ± 3.8. The authors do not provide specific age estimations per sun exposure group. The mean UV index for Copenhagen, Denmark, is 2.69.

Mayes et al[9] evaluated a group of 239 Asian women living in Shanghai, China. Sun exposure was indirectly evaluated using a photodamage scale. Composite images were created for women that looked younger and older for their chronological age. Each image was composed of 14 different images, and all women had an average chronological age of 61 years.

The group with the higher perceived age had a photodamage score of 7.41, while the group with the lower perceived age had a score of 6.14, a statistically significant difference ($p < 0.001$). The authors also found a strong and statistically significant correlation between the photodamage score and perceived age ($r = 0.960$; $p < 0.001$). Women that looked older for their age had a chronological age of 61.3 ± 1.72 and a perceived age of 66.87 ± 4.38. The mean UV index near Shanghai, China, is 5.30.

Mayes et al[10] then evaluated the same group of Asian women from Shanghai, China, to identify lifestyle factors associated with perceived age. Patients were surveyed on their occupational sun exposure (work/worked inside, equal time inside and outside, work/worked outside) and current sun exposure (not much time in the sun, some time in the sun, a lot of time in the sun). By performing multivariate regression analysis, the authors found occupational sun exposure was one of the variables that could be used as independent predictors of the difference between perceived and chronological age ($p < 0.001$). Considering this statistical analysis, the authors found that those who worked mostly outside looked 3.96 years older than those who worked mostly inside. Additionally, multiple linear regression models identified occupational sun exposure as one of the variables accounting for up to 36.5% of the variability in the difference between perceived and chronological ages ($p = 0.001$).

Flament et al[13] evaluated a group of 298 White women living in Montpellier, France. Based on a dermatologist's evaluation of sun behavior and the Sun Behavior Score history,[13] the patients were divided into sun-seeking and sun-phobic groups. Although the study did not provide mean chronological ages or mean perceived ages, it yielded the difference of both values for each age class studied (perceived age – real age [± standard error of mean]). The differences were significantly larger in the sun-seeking groups compared to sun-phobic groups ($p < 0.05$), except for the oldest patients (age ≥70), who generally looked younger. These data were illustrated in a bar graph, and therefore specific values cannot be accurately extracted. However, the largest mean difference was observed in the 40 to 49 age group (>4 years). The mean UV index near Montpellier, France, is 4.45.

Flament et al[14] evaluated a group of 301 Asian women living in Guangzhou, China. Based on sun behavior evaluation, the authors divided patients into normal exposure and sun-phobic groups. The methodology was the same as for their previous study in French women. Mean differences between chronological and perceived ages were also illustrated in a bar graph. Sun-phobic women were perceived overall to be younger than women in the normal exposure group. However, only those in age groups 20-29, 40-49, and 60-69 had a significantly higher difference in perceived age when compared to women in the normal exposure group ($p < 0.05$). The mean UV index near Guangzhou, China, is 2.77.

Gunn et al[15] evaluated a group of 329 Dutch women and 318 Dutch men from the Leiden Longevity Study living in different regions of Denmark and 162 English women for lifestyle factors that could be associated with sun exposure. The sun exposure status was surveyed with two questions regarding sun behavior in summer. Although overall patients were perceived to be younger for their chronological age, multivariate analysis of individual survey questions revealed that men who spent most of their time outside in summer were perceived to be significantly older than those who did not go outside much ($p = 0.046$), with a mean difference of 1.7 years in perceived age between the two groups. Additionally, women who sat in the sun while sunbathing were perceived to be significantly older than those who did not sit in the sun ($p = 0.013$), with a mean difference of 2.5 years in perceived age between the two groups.

Discussion

Normal facial aging results from the influence of several factors and forces, not only on the facial skin but also on the skeletal and adipose structures of the face.[16] Some of the characteristics associated with old skin are wrinkling, dryness, thinning, and seborrheic keratoses.[17] Fat redistribution and changes in the morphology of certain facial bones due to resorption also contribute to the face looking older.[16] On top of this, the DNA damage caused by UV radiation leads to the accelerated development of other characteristics associated with older age, such as hyperpigmentation and increased wrinkle formation.[17] In aging studies, researchers commonly use clinical scales based on a scoring system depending on the severity of facial characteristics, mainly dyspigmentation, wrinkling, and photodamage.[18] These characteristics are evaluated in the different facial areas (i.e., upper face, midface, lower face), either independently or in combination.[18] Ultimately, despite the existence of scales and criteria to describe the aging face, its evaluation remains a subjective topic.

Although a meta-analysis of the presented data was not possible due to the error propagation of measurements and the inability to perform accurate correlation analyses using arithmetic means, the data described throughout the review and the summary presented in ►**Table 3** show that patients residing in geographic areas with highest mean UV indexes are usually perceived as older for their chronological age than those in areas with low mean UV indexes (see ►**Fig. 4**).

The findings in this review support the hypothesis that increased UV exposure accelerates skin aging and show trends in perceived age based on the UV index of certain latitudes. Of great importance is the fact that there were no studies evaluating perceived age in tropical areas, known to have the highest UV indexes. Therefore, this review can also promote the study of perceived age in these regions so that information can be appropriately translated to these populations. The information provided in this review can serve as a starting point to support the creation of a large cross-sectional study specifically analyzing the relationship between UV index, chronological age, and perceived age. This would allow for an appropriate illustration of the data in a way that is visually appealing to both physicians and patients. However, an extensive number of patients would be needed to visually display those correlations. In a world where looking young for one's age is of importance to many, a

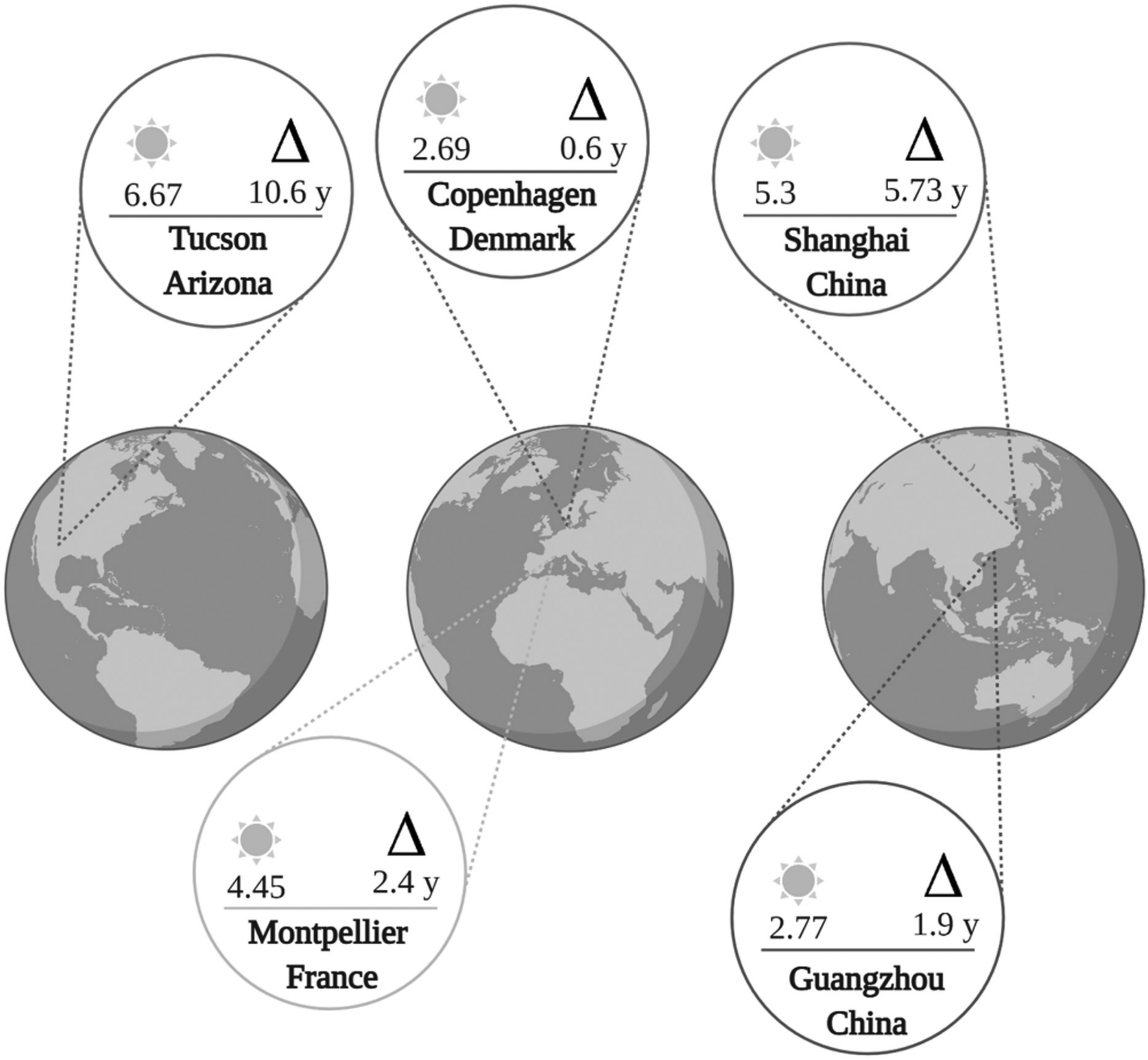

Fig. 4 Perceived age differences and ultraviolet (UV) indexes around the world. The figure shows the geographical location of the included studies, as well as the UV index and an approximate difference (not considering the standard deviations of the means) between perceived and chronologic age (Δ). The figure was created using www.Biorender.com.

graphic representation of these variables could motivate patients to improve skin care (see ►**Fig. 5**).

As has been the topic of this study, differences in skin aging are usually considered a result of environmental exposure, most notably, UV radiation. However, building on the knowledge of a genetic predisposition for skin aging,[19] a recent study by Roberts et al[20] proposed a genetic influence for the differences in perceived age. By conducting a genome-wide association study of more than 400,000 patients of the UK Biobank, the authors identified 74 loci associated with perceived age.[20] The identification of these specific loci and even molecular pathways involved in the characteristics of facial skin that render it susceptible to accelerated aging might allow patients to understand whether they are prone to look older and the preventive methods, pharmacological or behavioral, that they can follow to avoid this outcome.

Nevertheless, perceived age does not only serve as a motivator for patients to adopt healthier sun exposure behaviors but has also been shown to be a possible biomarker for overall mortality. Borkan et al[21] evaluated 1,086 men of the Baltimore Longitudinal Study of the Gerontology Research Center and found that older appearing men for chronological age (especially those aged 45- to 75-years-old) had an increased probability of mortality in the following years. Also, in their short report, Christensen et al[22] used data from the Longitudinal Study of Aging Danish Twins to specifically look for the relationship between perceived age and mortality. The authors found that 2 years after being evaluated, the older-looking twin of 49 pairs of twins had died. Additionally, Gunn et al[23] used the same database as Christensen et al[22] and found perceived age to be a survival predictor.

Even though only a handful of studies associate perceived age with mortality, the trend seems to follow a positive linear correlation. Therefore, the perceived age is not only an aesthetic subject but might also a serve as a biomarker. If this holds, living in a high UV index area could be considered

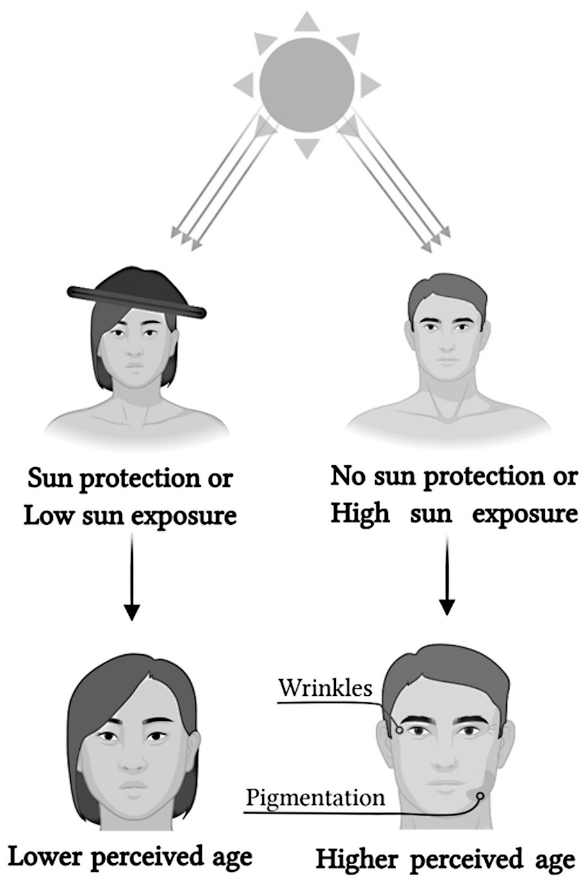

Fig. 5 Difference in sun exposure behaviors. People of the same chronologic age will have different perceived ages based on their behavior towards sun exposure. People using sun protection or having a lower sun exposure will look significantly younger than patients disregarding sun protection methods or with high sun exposure. The figure was created using www.Biorender.com.

a risk factor for overall mortality. However, since previous studies on mortality and perceived age only controlled for age and sex, several confounders could alter their stated results. Prospective studies following patients for years after an initial perceived age assessment could help examine the degree of its association with mortality by running a regression analysis and including other comorbidities, as well as other factors known to influence skin aging. In the future, with a large enough database, training of machine learning algorithms could help estimate a patient's age without the need for an external observer and compute it along with his or her risk factors to provide a more accurate mortality prediction.

Limitations

This study has several limitations. Since only studies published in English were included in this review, some studies may have been missed. Lack of information regarding the mean UV index for most locations is also considered a strong limitation. Thus, it was decided to use values from nearby places for which information was available. This decision poses a noteworthy bias since, though close, places can still differ in several variables (e.g., ozone layer thickness and altitude). Furthermore, using a single year's mean UV index was used as a surrogate for lifetime exposure, which is expected to impact the results. This decision was made due to information constraints. Although some studies detailed that the included patients had lived in the same region for all their life, this assumption had to be made for those who did not provide this information. Additionally, the decreased number of ethnicities examined in the included studies is also a considerable limitation. It is also essential to underscore that the differences in the definition of high sun exposure might be influencing the results. Although some studies stated that patients did not have any procedures aimed at rejuvenating their appearance (i.e., plastic surgery, hair dye), it is crucial to consider the possibility of the unknowing inclusion of this type of patients. Lastly, the heterogeneity in the studies' methodologies and the inclusion of groups who were evaluated differently poses another substantial limitation. Other limitations include the scarcity of studies reporting on this topic, the potential bias of misinterpreting data and results, and the study selection process, the latter being a potential source of bias common to systematic reviews.

Conclusion

Patients with high sun exposure behaviors living in areas with high UV indexes are commonly described as older for their chronological age than same aged peers with less sun exposure. A graphic representation of data comparing the difference in perceived and chronological age with different UV indexes for patients that use sun protection and patients that do not could help motivate patients living in high UV index areas to protect themselves from UV radiation.

Details of Earlier Presentation
This work was presented as an oral presentation at Plastic Surgery: The Meeting 2021 of the American Society of Plastic Surgeons (October 29th–November 1st, Atlanta, Georgia, United States).

Authors' Contribution
All authors contributed to the study conception and design. F.R.A., G.G., R.A.T.-G., and K.C.M. performed the literature search and wrote the initial draft. F.R.A. performed the eligibility assessment and data extraction. R.E. C., C.J.B., D.G., and A.J.F. critically revised the work. All authors read and approved the final manuscript.

Ethical Approval
This manuscript conforms to the Declaration of Helsinki.

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Conflict of Interest
None declared.

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