Clinical, Cosmetic and Investigational Dermatology

Dovepress
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ORIGINAL RESEARCH

Associations of Sleep Quality and Perceived Stress with Skin, Scalp, and Hair Health Among 1,017 Chinese Women: A Cross-Sectional Observational Study

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Background and Objective: Psychological stress and poor sleep quality are prevalent among urban adults and have been proposed to be associated with skin, scalp, and hair health through neuro-endocrine-immune pathways. However, evidence from large real-world cohorts under chronic, naturalistic conditions remains limited. The objective of this study was to characterize the associations of sleep quality and perceived stress with a range of dermatological outcomes under real-life conditions, including self-perceived concerns, expert-scored clinical signs, and objective instrumental measurement in healthy women.

Methods: This cross-sectional observational study enrolled 1,017 healthy women aged 18–40 years in Shanghai, China. Sleep quality was assessed with the Pittsburgh Sleep Quality Index (PSQI) and perceived stress with the Perceived Stress Scale (PSS-10). Dermatological outcomes were assessed through four modalities: validated psychometric questionnaires, self-perception surveys, expert clinical scoring, and objective instrumental measurements. Associations were investigated using generalized linear models (GLMs) adjusted for age and season (regression analytical sample: n=994 after exclusion of participants with BMI>30), with Benjamini–Hochberg correction for multiple comparisons.

Results: Poor sleep quality (PSQI score ≥ 6) was identified in 60% of participants and elevated perceived stress (PSS-10 score ≥ 14) in 50%. Both factors were significantly associated with lower wellbeing, happiness, and higher fatigue scores. Poor sleep quality was associated with increased likelihood of reporting sensitive scalp (OR = 1.17 [95% CI:1.08–1.27], Adj-P = 0.004), skin fatigue appearance (OR = 1.11 [95% CI:1.06–1.17], Adj-P = 0.003), and self-perceived skin yellowness (OR = 1.10 [95% CI:1.04–1.15], Adj-P = 0.013), as well as a modest but significant increase in clinically graded dark eye circle severity (β = 0.028 [95% CI: 0.012–0.044], Adj-P = 0.014). Elevated perceived stress was associated with self-reported hair loss (OR = 1.04 [95% CI:1.01–1.06], Adj-P = 0.034) and itchy scalp (OR = 1.07 [95% CI:1.03–1.11], Adj-P = 0.035). In post-hoc exploratory age-stratified analyses, poor sleep was associated with higher acne severity exclusively in participants aged 18–25 years (p = 0.016).

Conclusion: In this cross-sectional study of healthy urban women in Shanghai, poor sleep quality and elevated perceived stress were each associated with a range of self-perceived dermatological concerns and clinical signs. These findings are cross-sectional in nature and require longitudinal investigation to establish temporal directionality. The observed associations are consistent with the skin-brain axis hypothesis and support the relevance of sleep and stress assessment in dermatological research and practice.

Keywords: chronic psychological stress, sleep quality, skin, scalp, hair, clinical

https://doi.org/10.2147/CCID.S617950
Received: 18 April 2026
Accepted: 13 June 2026
Published: 7 July 2026

Introduction

The prevalence of psychological stress and sleep disorders has emerged as a growing public health concern, particularly among young generation such as college students[1] and some special occupational populations such as healthcare workers.[2] The COVID-19 pandemic even further exacerbated this burden globally.[3]

While the associations of psychological stress and poor sleep with systemic health outcomes are well documented,[4–9] their consequences for skin, scalp, and hair are increasingly recognized as clinically relevant.[10] Skin functions as a "trinity" of neuro–endocrine–immune system, communicating bidirectionally with the central nervous, endocrine and immune systems, maintaining its own homeostasis and influencing systemic homeostasis.[11] Dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis under conditions of chronic stress or sleep insufficiency, characterized by sustained elevation of cortisol and corticotropin-releasing hormone, has been proposed to impair cutaneous barrier integrity, modulate sebaceous gland activity, and alter hair follicle cycling.[12] The skin-brain axis provides a theoretical framework for understanding the relationships.

Sleep disorders and psychological stress have been associated with various changes in skin and scalp health. Studies indicate that sleep deprivation is associated with skin barrier dysfunction manifesting as increased trans-epidermal water loss (TEWL),[13] and has been documented in patients with atopic dermatitis and contact dermatitis.[14] Sleep disturbances are reported to affect 47–90% of patients with atopic dermatitis[15] and are prevalent among those with psoriasis.[16] Additionally, late bedtime has been linked to alterations of skin microbiome.[17] Acute stress responses has been associated with sweating, edema, and exacerbation of inflammatory skin conditions such as acne and rosacea.[18] Stress-induced elevation of glucocorticoid levels has been shown to delay wound healing, potentially contributing to hypertrophic scar formation.[19,20] The bidirectional relationship between skin lesions and psychological symptoms is well-established.

As a specialized skin region, the scalp exhibits unique sensitivity to both stress and sleep disruption, including the disruption of the hair growth cycle by acute stress through cortisol-mediated suppression of follicular proteoglycan synthesis and other scalp disorders.[21] Clinical observations suggest that acute stress can rapidly induce scalp sensitivity symptoms.[22,23] Epidemiological data indicate seborrheic dermatitis as a prevalent stress-related skin condition, the incidence of which has increased significantly over the past decade.[24] Psychological stress has been associated with inflammatory scalp conditions such as non-scarring folliculitis and telogen effluvium,[24] while sleep disorders have been associated with alopecia areata.[25] In vitro evidence further demonstrated that long-term circadian rhythm deregulation impairs the regenerative properties of hair follicle and skin precursor cells.[26]

Current research has predominantly relied on short-term sleep deprivation conditions to simulate sleep disorder effects,[13,27–29] which may inadequately reflect the dermatological consequences of the chronic, intermittent sleep impairment prevalent in everyday life. Furthermore, the association between chronic psychological stress exposure and sleep quality on dermatological outcomes demonstrates a more complex interaction patterns during naturalistic conditions than those observed under acute experimental paradigms.[30] Previous investigations examining sleep or psychological stress as isolated variables may underestimate the integrated dermatological consequences of their co-occurrence in real-life settings.

To address this gap, we conducted a cross-sectional observational study in a large cohort of healthy women in Shanghai (18–40 y.o)., assessing sleep quality and perceived stress levels using the validated Pittsburgh Sleep Quality Index (PSQI) and Perceived Stress Scale (PSS-10). Restricting enrolment to women aged 18–40 years was intended to minimize confounding from both chronological aging and the hormonal change of the menopausal transition. Dermatological outcomes were assessed through four modalities: validated psychometric questionnaires, self-perception surveys, expert clinical scoring, and objective instrumental measurements. The primary objective of the study was to characterize the associations between sleep quality and perceived stress and wellbeing indicators, self-perceived skin, scalp and hair concerns, clinically scored signs and instrumental measurements, specifically focusing on a general, healthy population in real-world settings.

Materials and Methods

Study Design and Participants

This was a cross-sectional observational study enrolling 1,017 healthy female volunteers aged 18 to 40 years, recruited between Dec. 2023 and Apr. 2024 at a single site in Shanghai, China. The cohort was designed to investigate chronic,

lifestyle-related dermatological associations while minimizing hormonal confounding. The restriction to women aged 18–40 years was motivated by two a priori considerations. First, to minimize the confounding influence of perimenopausal hormonal fluctuations on skin physiology, sebaceous activity, and sleep architecture, which occur with increasing variability from the early 40s onwards. Second, the cohort was restricted to women aged ≤40 years to focus on a population in whom lifestyle-driven dermatological variation is not yet dominated by chronological aging, the age ceiling of 40 years served as a pragmatic operational proxy for pre-menopausal status.

The cohort was stratified into four pre-specified, approximately balanced age groups (18–25, 26–30, 31–35, and 36–40 years) to enable age-stratified analyses of outcomes with known age-dependent prevalence trajectories (acne, skin elasticity and grey hair). A minimum residency of 5 years in Shanghai was required to ensure comparable long-term environmental exposome exposure (ambient air quality, ultraviolet radiation, lifestyle patterns) across participants.

Prior to participant enrollment, the study protocol was approved by the Ethics Committee. Written informed consent was obtained from all participants after they received a full explanation of the study objectives and procedures in accordance with the Declaration of Helsinki. As a non-interventional observational study, this study was not prospectively registered.

To ensure the homogeneity of the study population, the following inclusion and exclusion criteria were applied. Eligible volunteers self-reported being in good general health with no history of chronic medical or psychiatric conditions. Specific non-inclusion criteria included: 1) pregnancy or nursing; 2) menopausal or post-menopausal status; 3) moderate to severe dermatologic diseases (eg., skin cancer, autoimmune skin diseases); 4) systemic diseases, particularly endocrine disorders (eg., diabetes, polycystic ovary syndrome, thyroid dysfunction), hypertension, or diagnosed mental illnesses (eg., clinical depression, schizophrenia); 5) use of systemic medications (eg., anti-inflammatory drugs, corticosteroids, antibiotics, or hormonal therapies) within one month prior to inclusion; and 6) recent cosmetic procedures or chemical hair/scalp treatments (eg., medical beauty treatments within 6 months, or hair dyeing/bleaching within 3 months).

To ensure adequate representation of individuals at the high-stress tail of the PSS-10 distribution, which was sparsely populated in the naturally recruited sample, 53 additional participants were recruited via a targeted strategy. All 53 individuals were recruited based on self-reported "high stress" in response to a single screening question administered prior to validated scale completion. Among them, 23 individuals also concurrently reported "poor sleep" during the initial screening. This enrichment strategy was designed to enhance analytical representation of severe stress; however, it biases the prevalence estimates for the full enrolled cohort (n=1,017) towards higher rates of poor sleep and elevated stress relative to an unselected population sample. The primary association analyses were conducted on the full analytic sample (n=994), following the exclusion of 23 participants with a BMI > 30 kg/m^2. This threshold corresponds to the World Health Organization (WHO) classification for obesity, exclusion was implemented to mitigate the potential confounding effects of this condition, which is known to independently influence skin physiology, sleep quality, and systemic inflammatory status.

Data Collection Methodology

A multi-modal approach was utilized for data collection, integrating four modalities: validated psychometric questionnaires, self-perception surveys, expert clinical scoring, and objective instrumental measurements.

Validated Psychometric Questionnaires

Participants completed a comprehensive set of internationally validated questionnaires to evaluate their psychological state and lifestyle factors.

Sleep quality was evaluated using the Pittsburgh Sleep Quality Index (PSQI),[31] and perceived stress levels were assessed with the Perceived Stress Scale (PSS-10).[32] Broader psychological wellbeing was quantified using the Warwick-Edinburgh Mental Well-being Scale (WEMWBS),[33] subjective happiness was measured with the Subjective Happiness Scale (SHS),[34] and fatigue was assessed via the Fatigue Assessment Scale (FAS).[35]

Self-perceived immune status was assessed using a four-item module developed with reference to the immune domain of the Suboptimal Health Status Questionnaire (SHSQ-25).[36] This specific subset focuses on immune-related indicators, including one item on general health status (8-point scale: 1 = very bad, 8 = very good) and three items assessing symptom frequency over the past three months (5-point scale: 1 = Never or almost never, 5 = Always: "Suffered from a sore throat?", "Could not tolerate cold environments?", and "Caught a cold in the past 3 months?").

Self-Perception Surveys

To evaluate subjective cosmetic concerns and lifestyle factors, a detailed demographic and lifestyle questionnaire was administered to collect information on life habits, dietary patterns, exposome conditions (eg, daily commute time, UV protection and sunscreen use), occupation, sociodemographic characteristics, and basic physiological data including BMI.

A structured questionnaire was also used to assess perceived skin, scalp, and hair quality. Participants first defined their baseline typology, including skin/scalp/hair type (ranging from very dry to very oily), skin tone, and hair texture (thickness and hardness), using a single-choice scale. Additionally, specific concerns were evaluated across three domains: overall skin quality (41 items, eg., tone evenness, radiance, fatigue, yellowness, sensitivity); scalp quality (8 items eg., dandruff, itchiness, tightness, burning); and hair quality (20 items, eg., hair dullness, hair loss, texture). These concerns were assessed as binary (yes/no) responses. While these custom tools have not undergone formal external validation, they were developed based on established industry consumer-research protocols and have been used for years in the cosmetic industry to capture subjective concerns and daily routines.

Clinical Scoring Procedures

All visual evaluations of skin, scalp, and hair parameters were conducted by dermatologists and clinical experts. Each parameter was assessed and scored according to established clinical grading scales or published photographic atlases.[37–39]

Skin redness and dullness were graded using a 0–9 visual scale, based on the modified Griffiths 10-point scale (Table 1).[40] Acne severity was quantified with a 0–4 scale, referencing the IGA Acne Severity Scale.[41] Dark eye circle severity, categorized into pigmentary and vascular types by a dermatologist, was assessed on a 0–4 scale, guided by respective atlases according to the five-point visual assessment scale. To enhance scoring precision, half-point scores (0.4 or 0.6) were employed when deemed necessary.

Grey hair was visually evaluated against a standardized 0% to 100% scale (comprising 20 hair swatches representing 5% increments of greying) across five designated scalp areas (forehead, left and right temple, vertex, and nape), and an average score was subsequently derived.[42] Scalp greasiness was assessed using a four-point categorical scale, ranging from 0 (none) to 3 (severe).

Instrumental Measurements

Prior to all measurements, participants were required to acclimatize for at least 30 minutes in a temperature and humidity-controlled room (eg 22 ± 2°C, 50 ± 10% RH). Objective biophysical parameters of the skin and scalp were then quantified using a suite of non-invasive dermatological devices.

On the forehead, casual sebum level was measured using a Sebumeter SM 815 (Courage + Khazaka Electronic GmbH, Cologne, Germany). On the cheeks, according to a side randomization, skin elasticity was evaluated with a Cutometer (Courage + Khazaka Electronic GmbH, Cologne, Germany) and transepidermal water loss (TEWL) was quantified with a VapoMeter (Delfin Technologies Ltd, Kuopio, Finland); skin tone was determined using a Chromameter CR-400 (Konica Minolta Inc, Tokyo, Japan).

Table 1 Clinical Grading Criteria and Scoring System for Skin Redness and Skin Dullness, Based on Modified Griffiths 10-Point Visual Scale

Parameter	None (=0)	Mild (1–3)	Moderate (4–6)	Severe (7–9)
Skin redness	No redness on test area	Slight redness on test area	Moderate redness on test area	Severe redness on test area
Skin dullness	Extremely radiant, luminous or glowing appearance all over the tested area	Adequate to acceptable radiance, most areas with visibly radiant and glowing appearance	Perceivable to slight radiance	Very slight radiance or extreme dull appearance, skin is heavily dull and matte, no visible luster

For scalp measurements, sebum (Sebumeter), TEWL (VapoMeter), and surface temperature (Thermometer ST500; Courage + Khazaka Electronic GmbH, Cologne, Germany) were quantified at two designated sites on the left and right hemispheres of the scalp.

Statistical Analysis

Frequencies and descriptive statistics were calculated for the full cohort (n = 1,017). Pearson correlation coefficients were computed to assess the relationships between wellbeing indicators, sleep scores, and stress scores, given the large sample size which satisfies the normality assumption; results were visually depicted in a heatmap. To investigate the associations between specific concerns on the full analytic sample (n=994, following the exclusion of 23 participants with a BMI > 30 kg/m^2, see *Study Design and Participants*), generalized linear models (GLMs) were fitted for all possible pairs of variables, with adjustment for age (continuous) and season (binary: 0 = Spring, 1 = Winter). The outcome variable (y) was modeled as a function of the predictor variable (x), age, and season (y ~ x + age + season). Depending on the nature of the outcome, either binomial (for binary outcomes) or Gaussian (for continuous outcomes) GLMs were used. For binary outcomes, the Odds Ratio (OR) and its 95% confidence interval (CI) were calculated to quantify the multiplicative increase in the odds of the outcome for each 1-unit increase in the predictor. For continuous outcomes, the Beta coefficient (β) and its 95% confidence interval (CI) were calculated to quantify the additive association between the predictor and the outcome. A total of 199,328 regression models were executed. For each model, the p-value corresponding to the predictor (x) was retained and adjusted for multiple comparisons using the Benjamini–Hochberg (BH) procedure to control the false discovery rate. Outcomes were considered significantly associated with sleep or stress if, in models where x was the PSQI total score (sleep) or the PSS-10 total score (stress), the BH-adjusted p-value for x was < 0.05 after adjustment for age and season. Power analyses indicated that the sample size was sufficient to detect small effects in Gaussian GLM analyses. For binomial GLMs, the sample provided adequate sensitivity to detect small-to-moderate associations for outcomes with moderate prevalence.

For a selection of clinically meaningful indicators identified by clinicians, such as acne, loss of skin elasticity, and grey hair, further focused analyses were performed. Participants were stratified into four distinct age groups (18–25, 26–30, 31–35, and 36–40 years). Within each age stratum, pairwise independent *t*-tests were conducted to compare these selected indicators across different sleep quality groups (0–4, 5–8, 9–12, 13–21) and stress level groups (0–10, 11–20, 21–40). These analyses were not pre-specified within the primary GLM framework and no correction for multiple comparisons was applied. A p-value threshold of <0.05 was used; all findings from these analyses are considered exploratory indicators of potential association and require independent replication before clinical interpretation.

All statistical analyses were conducted in RStudio with R version 4.2.2 (Windows), using the stats::glm function (R stats package, version 4.2.2).

Results

Population Characteristics

The demographic and baseline characteristics of the 1,017 participants, together with the distribution of sleep quality and perceived stress levels across age groups, are presented in Table 2.

Sleep and Stress Status in the Cohort

Initial analysis of the full cohort revealed that both sleep quality (Figure 1A) and perceived stress (Figure 1B) levels followed a normal distribution. Despite this distribution, a significant portion of the population experienced suboptimal wellbeing. Based on the Pittsburgh Sleep Quality Index (PSQI), 60% of participants were classified as having poor sleep quality (PSQI score ≥ 6). Concurrently, assessment with the Perceived Stress Scale (PSS-10) indicated that 50% of the cohort reported medium-to-high levels of stress (PSS-10 score ≥14).

The recruitment strategy, including the targeted enrichment of 53 high-stress participants, is described in the Methods section. These figures include 53 specially recruited participants and overestimate prevalence relative to an unselected population sample.

Table 2 Distribution of Sleep Quality (PSQI) and Perceived Stress (PSS-10) Score Categories by Age Group (n=1,017)

	PSQI/PSS-10 Score Category	Age 18–25 (n = 260)	Age 26–30 (n = 252)	Age 31–35 (n = 253)	Age 36–40 (n = 252)
Sleep distribution	Good Sleep (PSQI 0–5)	105	97	87	88
	Poor Sleep (PSQI 6–21)	155	151+4*	155+11*	126+38*
Stress distribution	Low Stress (PSS-10 0–13)	122	116+1*	117+4*	106+7*
	Moderate Stress (PSS10 14–26)	135	127+3*	121+7*	106+27*
	High Stress (PSS-10 27–40)	3	5	4	2+4*

Notes: The table displays the number of participants within each PSQI and PSS-10 score category, stratified by four pre-specified age groups. The full enrolled cohort (n=1,017) includes 53 participants from a targeted special recruitment group, described in detail in the Study Design and Participants section of the Methods. * Values presented as X+n indicate a combination of participants from the main recruitment cohort (X) and the special recruitment group (n). Special recruitment participants were identified via a single self-report screening question and subsequently assessed using the validated PSQI and PSS-10 scales, their scale-derived scores are reflected in the category to which they were assigned.

Intercorrelation of Sleep, Stress, and Other Wellbeing Indicators

Linear correlation analysis revealed a significant network of relationships between sleep, stress and other key indicators (Figure 2). A direct positive correlation was observed between sleep quality (PSQI) and perceived stress (PSS-10) scores, as shown in the scatter plot (Figure 2A).

The correlation matrix in Figure 2B further confirmed that both poor sleep and higher stress were significantly associated with negative outcomes. Specifically, higher PSQI and PSS-10 scores were strongly correlated with lower wellbeing (WEMWBS; r = −0.33 and r = −0.53, respectively) and lower happiness (SHS; r = −0.33 and r = −0.55, respectively). Conversely, both poor sleep and high stress showed a strong positive correlation with high fatigue scores (FAS; r = 0.41 and r = 0.52, respectively). These findings are consistent with sleep and stress being central, interconnected components of overall wellbeing.

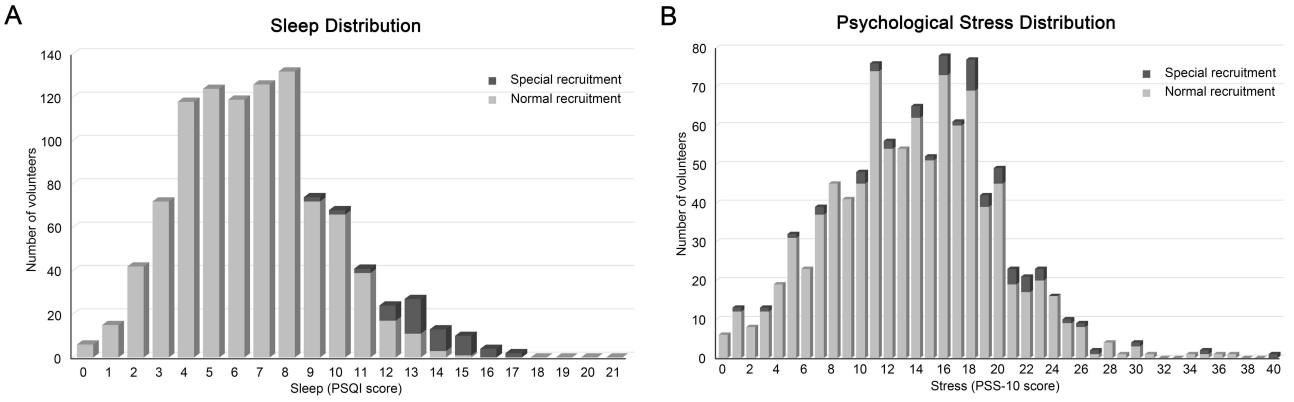

Figure 1 Distribution of sleep quality and perceived stress scores across the study cohort. Histograms show the distribution of scores for (**A**) sleep quality, as measured by the Pittsburgh Sleep Quality Index (PSQI), and (**B**) perceived psychological stress, as measured by the Perceived Stress Scale (PSS-10). The bars differentiate between participants from the normal recruitment cohort (light grey) and the special recruitment group (black), which comprised 53 individuals who self-reported high stress and/or poor sleep via a single screening question, recruited to enrich the high-scoring tail of the PSS-10 distribution (see Methods for details).

https://doi.org/10.2147/CCID.S617950

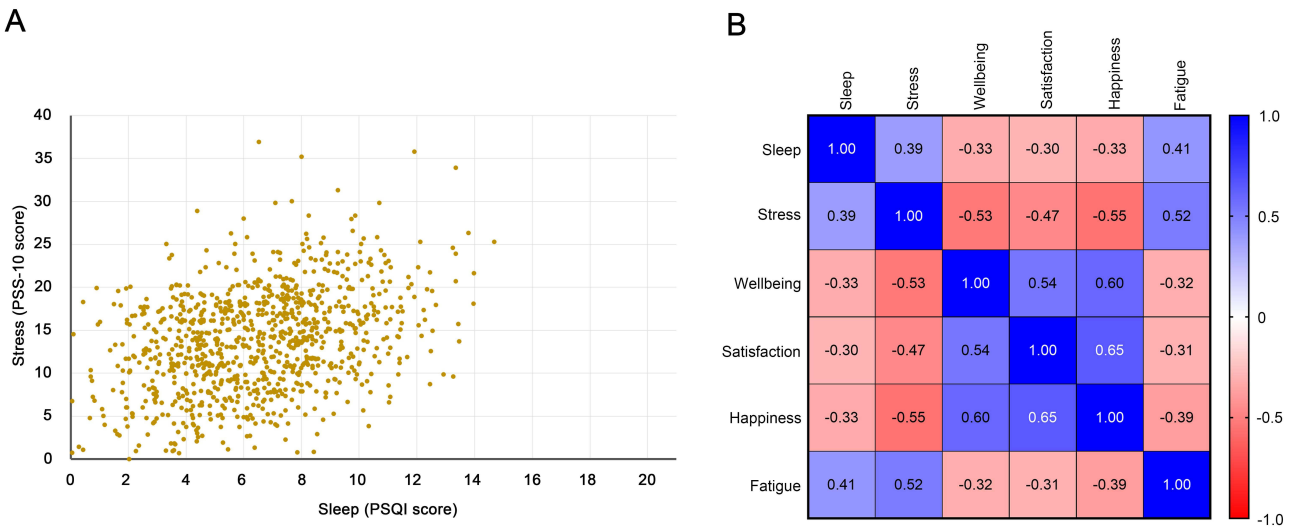

Figure 2 Associations between sleep quality, perceived stress, and other wellbeing indicators. (**A**) Scatter plot illustrating the positive association between sleep quality scores (PSQI) and perceived stress scores (PSS-10), where higher scores indicate poorer sleep and higher stress, respectively. (**B**) Correlation matrix heatmap visualizing the intercorrelations among all measured wellbeing indicators. Blue cells indicate a positive correlation, while red cells indicate a negative correlation, with color intensity representing the strength of the association. The values within the cells represent the Pearson correlation coefficients (r).

Associations Between Sleep Quality/Perceived Stress and Self Perceived General Health and Immune-Related Complaints

Beyond psychological wellbeing, we further examined associations between sleep quality or perceived stress and self-perceived physical health and immune-related complaints. A significant negative correlation was found between PSQI or PSS-10 scores and general self-reported immune-related complaints. Participants with poorer sleep or higher stress levels reported worse self-perceived physical health status (Figure 3A and E).

Furthermore, a clear graduated pattern of association was observed between poor sleep/high stress and a higher frequency of immune-related complaints. Participants with poorer sleep quality more frequently reported sore throat, cold intolerance, and catching colds (Figure 3B–D). An identical pattern was observed for participants with higher stress levels across the same three indicators (Figure 3F–H).

Collectively, these findings are consistent with an association between poor sleep or elevated stress and both a lower perception of overall health and a higher frequency of symptoms associated with a compromised immune response.

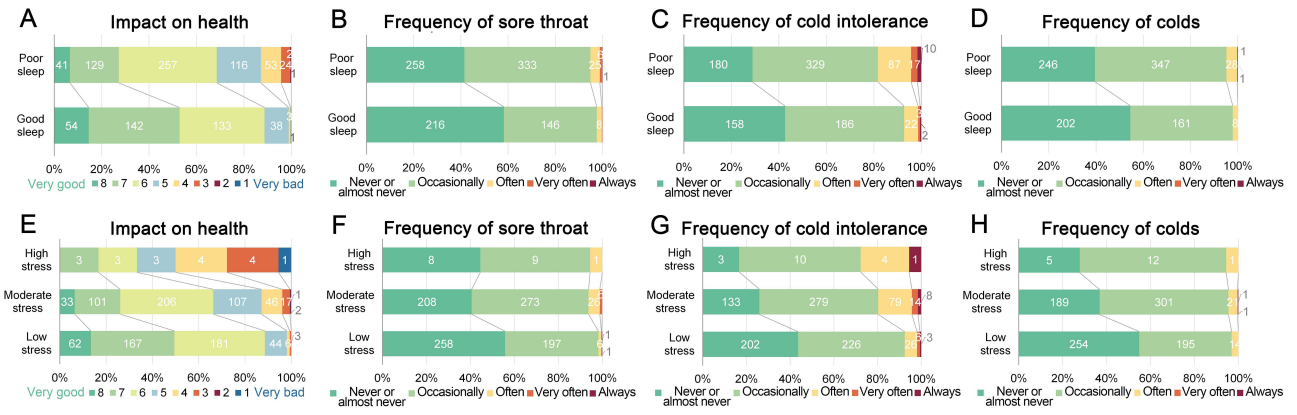

Figure 3 Associations between sleep quality or perceived stress and self-reported general health and immune-related complaints. The figure illustrates the distribution of self-reported responses to questions on general health and immune-related complaints, stratified by sleep quality (**A–D**) and perceived stress levels (**E–H**). Panels A–D compare responses between good sleepers (PSQI ≤5) and poor sleepers (PSQI ≥6). Panels E–H compare responses across low (PSS-10 ≤13), moderate (PSS-10 14–26), and high (PSS-10 ≥27) stress groups. These data were collected using an unvalidated custom questionnaire and reflect subjective symptom burden rather than immunological assessment.

https://doi.org/10.2147/CCID.S617950

Associations Between Sleep Quality and Skin, Scalp, and Hair Outcomes

To investigate the dermatological associations of poor sleep quality, both clinically scored signs and self-perceived concerns were evaluated against PSQI scores using generalized linear models (GLMs), adjusted for age and season.

A statistically significant association was observed between poorer sleep and the clinically graded severity of dark eye circles: each one-point increase in the PSQI score, dark eye circle severity was associated with an increase of β=0.028 (95% CI: 0.012–0.044, Adj-P=0.014)

Poor sleep quality was also associated with a range of self-perceived skin, scalp, and hair concerns (Table 3). Each one-point increase in the PSQI score was associated with an increased likelihood of reporting skin fatigue appearance (OR=1.11 [95% CI: 1.06–1.17], Adj-P=0.003), skin yellowness (OR=1.10 [95% CI: 1.04–1.15], Adj-P=0.013), and dull hair (OR=1.09 [95% CI: 1.04–1.16], Adj-P=0.028). Scalp outcomes showed the strong associations: sensitive scalp (OR=1.17 [95% CI: 1.08–1.27], Adj-P=0.004), itchy scalp (OR=1.20 [95% CI: 1.10–1.30], Adj-P=0.002), scalp pimples (OR=1.16 [95% CI: 1.07–1.25], Adj-P=0.008). Associations with scalp tightness (OR=1.29 [95% CI: 1.11–1.49], Adj-P=0.024) and dandruff (OR=1.19 [95% CI: 1.08–1.31], Adj-P=0.012) were statistically significant but were assessed only in the sensitive scalp subgroup (n=91) and should be treated as hypothesis-generating. Crude Relative Risks comparing poor sleepers to good sleepers are provided in Table 3 as descriptive estimates.

Notably, participants with poor sleep (PSQI ≥6) reported a higher prevalence of skin yellowness (32%) than good sleepers (18%); yet, no corresponding statistically significant change in chromameter b* values was detected instrumentally. This discordance is discussed in the Discussion.

Across all significant associations, poor sleepers showed consistently higher prevalence of skin, scalp, and hair concerns compared to good sleepers, with crude Relative Risks ranging from 1.78 (skin yellowness) to 2.67 (scalp pimples) across skin, scalp, and hair outcomes. Full prevalence figures and crude RR values for each outcome are presented in Table 3.

Table 3 Associations Between Sleep Quality and Self-Perceived Skin, Scalp, and Hair Concerns, Assessed Using Generalized Linear Models (GLM) Adjusted for Age and Season (n=994)

Skin/Scalp/Hair Concerns		Good Sleepers (Sleep Score≤5)	Poor Sleepers (Sleep Score≥6)	OR†	95% CI	Adj-P†	Crude RR‡
Skin concerns	Skin yellowness	18%	32%	1.10	1.04–1.15	0.013	1.78
	Skin fatigue appearance	10%	21%	1.11	1.06–1.17	0.003	2.10
Scalp concerns	Sensitive Scalp	3% (n=28)	6%	1.17	1.08–1.27	0.004	NA
	Scalp pimples	3% (n=28)	8%	1.16	1.07–1.25	0.008	2.67
	Scalp breakout acne	3% (n=28)	7%	1.15	1.06–1.25	0.016	2.33
	Itchy scalp *(under sensitive scalp*)*	2% (n=24)	5%	1.20§	1.10–1.30	0.002	NA
	Scalp tightness *(under sensitive scalp*)*	1% (n=6)	2% (n=16)	1.29§	1.11–1.49	0.024	NA
	Dandruff *(under sensitive scalp*)*	2% (n=17)	4% (n=44)	1.19§	1.08–1.31	0.012	NA
Hair concerns	Hair Dullness	10%	19%	1.09	1.04–1.16	0.028	1.90

Notes: * n=91 participants reported a sensitive scalp and were therefore included in the analysis of scalp sensitivity-specific sub-items (scalp tightness, scalp burning, itchy scalp, and dandruff. † Odds Ratio (OR) is derived from a binomial GLM with PSQI total score as a continuous predictor, adjusted for age and season; the OR represents the multiplicative change in the odds of reporting each concern for each one-point increase in the PSQI score. P-values were adjusted for multiple comparisons using the Benjamini–Hochberg procedure to control the false discovery rate; only associations with Adj-P <0.05 are reported. ‡ Crude Risk Ratio (RR): crude relative risk computed as P_1/P_0 (prevalence in Poor Sleepers divided by prevalence in Good Sleepers), provided for descriptive purposes and clinical interpretability, no formal hypothesis test was performed for this estimate. Crude RR was not calculated for scalp sub-items due to very small cell sizes (<10%). OR and crude RR are not interchangeable metrics and should not be directly compared. § Itchy scalp, scalp tightness and dandruff were assessed only among the n=91 participants who self-reported a sensitive scalp. The small cell sizes observed in these rows limit the precision of the estimates, while associations reached statistical significance after BH correction, these findings are considered hypothesis-generating only and require replication in larger cohorts.

Associations Between Perceived Stress and Scalp and Hair Outcomes

We also analyzed the association between perceived stress (PSS-10 score) and the prevalence of specific scalp and hair concerns, using GLMs adjusted for age and season (Table 4).

Higher perceived stress was significantly associated with an increased likelihood of self-perceived hair loss (OR=1.04 [95% CI: 1.01–1.06], Adj-P=0.034) and scalp itchiness (OR=1.07 [95% CI: 1.03–1.11], Adj-P=0.035). Associations with scalp tightness (OR=1.13 [95% CI: 1.06–1.21], Adj-P=0.010) and scalp burning (OR=1.18 [95% CI: 1.07–1.30], Adj-P=0.022) were statistically significant but derived from a very small subgroup (n=22 and n=8 respectively, each <5% of the analytic sample); these findings are hypothesis-generating only.

Associations Between Sleep Quality, Perceived Stress, and Skin and Scalp Sensitivity

A GLM analysis, adjusted for age and season, evaluated the association between sleep quality (PSQI), perceived stress (PSS-10), and self-reported sensitivity of the skin and scalp (Table 5).

Table 4 Associations Between Perceived Stress Level and Self-Reported Scalp and Hair Concerns, Assessed Using Generalized Linear Models (GLM) Adjusted for Age and Season (n=994)

Scalp & Hair Concerns		Low Stress (PSS-10 0–13)	Moderate Stress (PSS-10 14–26)	High Stress (PSS-10 27–40)	OR†	95% CI	Adj-P†	Crude RR‡
Scalp concern (*under sensitive scalp**)	Itchy scalp	3% (n=26)	5% (n=49)	0 (n=2)	1.07§	1.03–1.11	0.035	N/A
	Scalp tightness	1% (n=6)	1% (n=15)	0 (n=1)	1.13§	1.06–1.21	0.010	N/A
	Scalp burning	0 (n=1)	1% (n=6)	0 (n=1)	1.18§	1.07–1.30	0.022	N/A
Hair concern	Hair loss	27%	34%	1%	1.04	1.01–1.06	0.034	1.26

Notes: * n=91 participants reported a sensitive scalp and were therefore included in the analysis of scalp sensitivity-specific sub-items (itchy scalp, scalp tightness, and scalp burning). † Odds Ratio (OR) is derived from a binomial GLM with PSS-10 total score as a continuous predictor, adjusted for age and season, the OR represents the multiplicative change in the odds of reporting each concern for each one-point increase in the PSS-10 score. P-values were adjusted for multiple comparisons using the Benjamini–Hochberg procedure to control the false discovery rate, only associations with Adj-P <0.05 are reported. ‡ Crude Risk Ratio (RR): crude relative risk computed as P_1/P_0 (prevalence in moderate stress group divided by prevalence in low stress group), provided for descriptive purposes and clinical interpretability; no formal hypothesis test was performed for this estimate. As hair loss prevalence exceeded 10% in the moderate stress group (34%) and low stress group (27%), the crude RR is additionally reported to provide a more directly interpretable measure of association between stress groups, computed as P_1/P_0 (prevalence in Moderate stress divided by prevalence in Low stress). Crude RR was not calculated for scalp sub-items due to very small cell sizes (<10%). OR and crude RR are not interchangeable metrics and should not be directly compared %. § Scalp tightness, scalp burning, and itchy scalp were assessed only among participants who self-reported a sensitive scalp (n= 91). The small cell sizes observed in these rows limit the precision of the estimates; while associations reached statistical significance after BH correction, these findings are considered hypothesis-generating only and require replication in larger cohorts.

Table 5 Associations Between Sleep Quality (PSQI) or Perceived Stress (PSS-10) and Self-Reported Sensitive Skin and Sensitive Scalp, Assessed Using Generalized Linear Models (GLMs) Adjusted for Age and Season (n=994)

Correlation	OR†	95% CI	P-value‡	Adj-P‡
Sensitive skin x PSQI*	1.06	1.01–1.12	0.019	0.282
Sensitive scalp x PSQI	1.17	1.08–1.27	8.37×10^{-5}	0.004
Sensitive skin x PSS-10*	1.04	1.01–1.06	0.003	0.065
Sensitive scalp x PSS-10	1.05	1.02–1.09	0.004	0.098

Notes: * Association did not reach statistical significance after Benjamini–Hochberg correction for multiple comparisons (Adj-P >0.05); included here to present the full pattern of associations between sleep quality or perceived stress and skin and scalp sensitivity. † OR is derived from a binomial GLM with PSQI total score (sleep) or PSS-10 total score (stress) as a continuous predictor, adjusted for age and season; the OR quantifies the multiplicative change in the odds of reporting sensitive skin or scalp for each one-point increase in the predictor score. ‡ Both uncorrected P-values and BH-adjusted P-values (Adj-P) are presented. Statistical significance was defined as Adj-P <0.05.

The most statistically robust association was observed between poor sleep quality and sensitive scalp: each one-point increase in PSQI score was associated with 17% increased likelihood of reporting sensitive scalp (OR = 1.17 [95% CI: 1.08–1.27], Adj-P = 0.004).

Other associations, while directionally consistent with a priori expectations, did not reach the threshold for statistical significance after BH correction. Higher stress levels showed a trend toward association with sensitive skin (Adj-P = 0.065) and sensitive scalp (Adj-P = 0.098). The association between poor sleep and sensitive skin was not statistically significant (Adj-P = 0.282).

Post-Hoc Exploratory Age-Stratified Analyses of Specific Clinical Signs

Recognizing that the prevalence of certain clinical signs such as acne, loss of skin elasticity, and grey hair is strongly age-dependent, these post-hoc exploratory age-stratified analysis were performed to better isolate the association of lifestyle factors with dermatological outcomes from natural aging.

A progressive reduction in skin elasticity (Cutometer R2 parameter) with worsening sleep scores was observed in the 18–25, 26–30, and 31–35 age groups ($p<0.01$ for the 18–25 and 26–30 age groups, and $p<0.001$ for the 31–35 age group), but not in the 36–40 age group. In the 18–25 age group, poorer sleep was associated with a significantly higher proportion of elevated acne scores ($p=0.016$); this association was not observed in older groups. Within the 18–30 age group, higher stress levels were associated with increased grey hair prevalence and severity ($p=0.04$); this association was absent in the 31–40 age group. The absence of significant associations in the 36–40 age group may reflect floor or ceiling effects (age-related skin changes masking lifestyle stressor effects), or genuine biological attenuation of these associations at older ages. All age-stratified findings are designated exploratory, they were conducted without correction for multiple comparisons and require independent replication (Figure 4).

Discussion

Before discussing individual dermatological outcomes, it is worth establishing that the key descriptive findings of this cohort are well-aligned with published data, supporting the validity and relevance of the dataset. The high prevalence of poor sleep quality (PSQI ≥6 in 60% of the enrolled cohort) is consistent with data from prior studies in young adult Chinese populations and specific occupational groups in which PSQI-defined poor sleep has been reported in 45–65% of participants.[43,44] Furthermore, the observed associations between PSQI and PSS-10 scores and validated wellbeing instruments, including negative correlations with WEMWBS ($r=-0.33$ and $r=-0.53$, respectively) and subjective happiness ($r=-0.33$ and $r=-0.55$, respectively), and positive correlations with fatigue ($r=0.41$ and $r=0.52$, respectively), are consistent with the well-established bidirectional relationship between sleep, stress, and psychological wellbeing,[45] confirming that the psychometric profiles of this cohort follow expected patterns. These findings validate the dataset as a relevant and representative basis for examining downstream dermatological associations.

The association between poor sleep and dark eye circles represents perhaps the most intuitive link between sleep disturbance and skin appearance, one that is widely assumed yet rarely quantified in healthy, real-world populations. In this cross-sectional study of 994 healthy urban Chinese women experiencing habitual, chronic sleep variation rather than acute deprivation, a statistically significant but modest association was confirmed between PSQI-measured sleep quality and clinically graded dark eye circle severity ($\beta=0.028$, Adj-P=0.014). The modest magnitude of this effect is itself informative: it suggests that the sleep–dark circle relationship, while intuitive, is less straightforward to demonstrate at the population level under chronic real-life conditions than experimental acute deprivation studies might imply, particularly in a healthy cohort aged 18–40 years. Beyond this primary clinical sign, the most statistically significant association in this dataset was observed between poor sleep quality and self-reported sensitive scalp (OR=1.17, Adj-P=0.004). Additional self-perceived concerns including skin fatigue appearance, skin yellowness, dull hair, and multiple scalp symptoms were associated with both poor sleep and elevated stress, with odds ratios in the range of 1.04–1.29.

A critical contextual distinction for interpreting the dermatological findings of this study is that the existing literature on sleep and skin is dominated by two types of study designs that differ substantially from our approach: acute experimental sleep deprivation paradigms and investigations in clinical populations with dermatological or psychiatric disease. Léger et al demonstrated that short-term sleep restriction altered facial skin barrier parameters and lipid

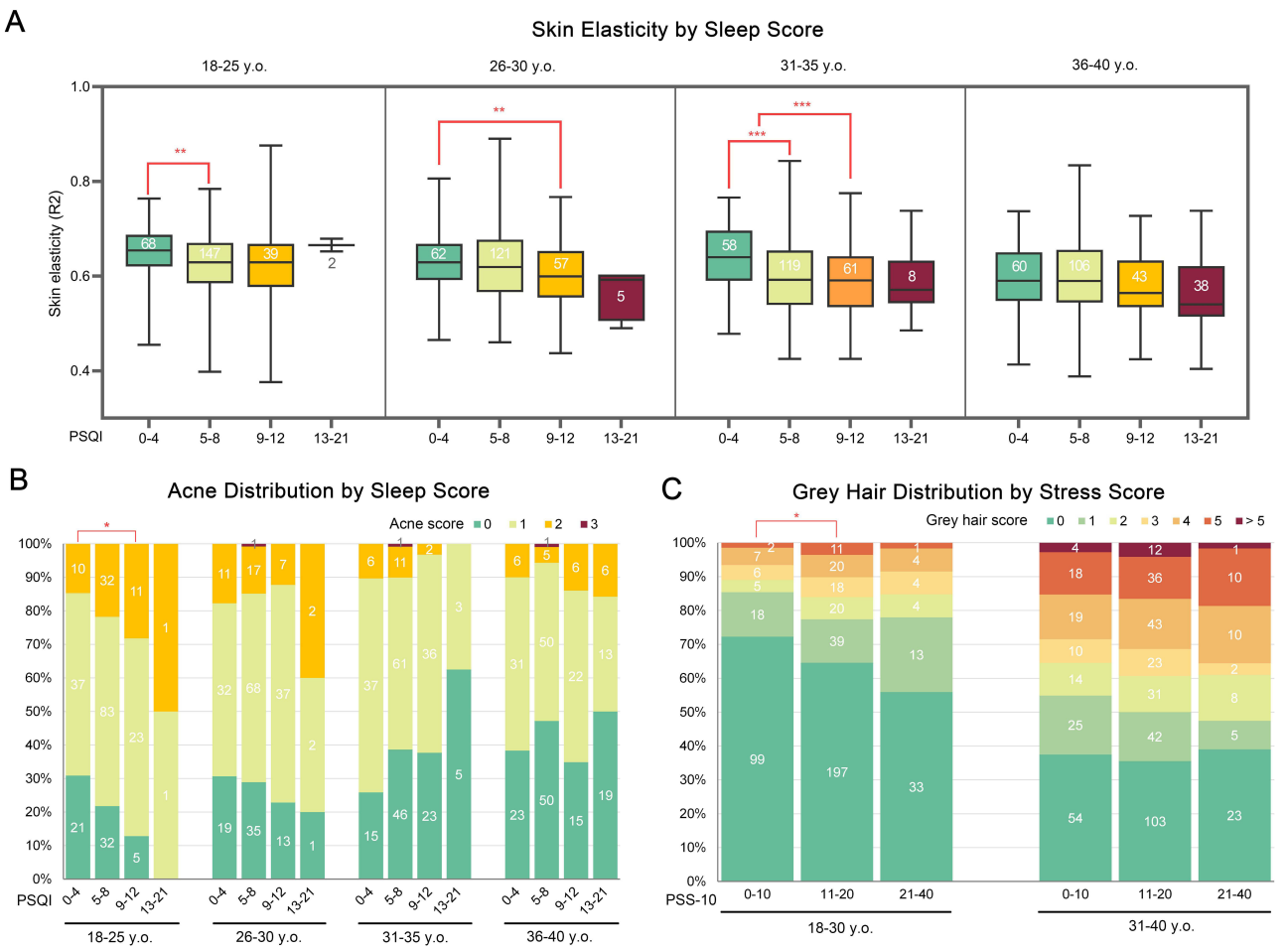

Figure 4 Age-stratified exploratory analyses of associations between sleep quality or perceived stress and specific clinical skin and hair parameters (**A**) Boxplot analysis illustrating the association between sleep quality (PSQI score) and skin elasticity (Cutometer R2 parameter) across four age groups. A progressive reduction in skin elasticity with worsening sleep scores was observed in the 18–25, 26–30, and 31–35 year age groups (**p<0.01, ***p<0.001), but not in the 36–40 age group. The absence of a statistically significant association in the 36–40 age group may reflect floor or ceiling effects whereby the dominant influence of chronological aging on elasticity loss masks the comparatively modest contribution of sleep disturbance. (**B**) Distribution of acne scores by sleep quality groups across four age groups. A statistically significant association between poorer sleep and a higher proportion of elevated acne scores was observed only in the 18–25 year cohort (p=0.016); no significant association was observed in older age groups. (**C**) Distribution of grey hair scores by perceived stress (PSS-10 score) groups. A statistically significant association between higher stress levels and increased grey hair prevalence was observed only in the 18–30 year age group (p=0.04); this association was absent in the 31–40 year age group. Asterisks denote statistically significant differences (*p<0.05, **p<0.01, ***p<0.001). **Notes**: The above analyses were post-hoc, not pre-specified, and were conducted without correction for multiple comparisons; findings should be considered exploratory and require independent replication before clinical interpretation.

peroxidation in 24 women,[28] while Kim et al reported impaired skin biophysical parameters following acute one night total sleep deprivation.[13] Matsubara et al documented a significant increase in imaging facial skin yellowness and a decrease of skin hydration following acute total sleep deprivation, with recovery in few days.[29] In contrast, the present study was conducted in a healthy general population experiencing habitual, chronic sleep variation rather than acute total deprivation, a condition substantially more prevalent in everyday life yet far less studied in the dermatological context. The dermatological associations observed here were present but of modest magnitude, consistent with the expectation that chronic, low-amplitude sleep impairment in a non-clinical population produces subtler changes than acute total deprivation. These findings are therefore more broadly applicable to the general population than those derived from experimental or disease-based settings.

One notable finding is the observed discrepancy between self-perceived stress and sleep status as captured by a single screening question, and the objective classifications derived from the validated PSS-10 and PSQI scales. While the targeted recruitment strategy successfully enriched the cohort with individuals experiencing higher stress, it also underscored the inherent limitations of single-item self-assessment. This disparity likely stems from the difference between

https://doi.org/10.2147/CCID.S617950

a subjective self-label and a multi-faceted, validated psychometric instrument that probes the frequency of specific feelings over time. From a methodological standpoint, this finding reinforces the importance of validated, multi-item questionnaires for exposure classification in studies of this kind, in preference to single screening questions.

The discordance between self-perceived skin yellowness (significantly associated with poor sleep, OR=1.10, Adj-P=0.013) and the absence of a significant chromameter b* change warrants specific consideration, particularly in the context of our real-world population where changes are expected to be subtler than those observed following acute deprivation. This discordance is most plausibly attributed to a limitation of point-source chromametric measurement (3mm spot size) in capturing broad facial color perception, the instrument assesses a restricted area and may lack the sensitivity to detect diffuse, low-amplitude color changes across the full facial surface. Alternatively, perceived yellowness may reflect a composite of attributes (including radiance, microtextural uniformity, and microcirculatory changes) not fully captured by b* alone. Both explanations are consistent with prior observations that subjective facial appearance ratings integrate multiple skin optical properties beyond individual colorimetric parameters.[46] This discordance is acknowledged as a limitation of the current methodology. Future studies should consider complementary full-face spectroscopic or expert clinical assessment of skin color to address the constraints of single-point chromametric measurement.

The post-hoc exploratory age-stratified analyses suggested the associations between poor sleep and higher acne scores were confined to the 18–25 age group, an exploratory finding that is biologically plausible, as this demographic has a higher baseline prevalence of acne,[47,48] and poor sleep may act as an exacerbating factor. Conversely, the associations of sleep and stress with signs intrinsically linked to natural aging, such as loss of skin elasticity and the incidence of grey hair, were less apparent in the older cohorts. The absence of significant associations in the 36–40 age group may reflect floor or ceiling effects in which age-related skin changes mask the more subtle influence of lifestyle stressors, or genuine biological attenuation of these associations at older ages. All age-stratified findings are designated as exploratory, paving the way for future independent replication in larger, pre-specified cohorts to solidify these clinical insights.

The current cohort was restricted exclusively for female participants. While this design choice ensured internal homogeneity and reduced sex-related confounding in the dermatological and psychometric outcomes, it precludes generalization of these findings to the male population. Sex-related differences in sleep architecture, stress physiology, sebaceous gland activity, and skin barrier function are well-documented,[49–54] and the extent to which the associations observed here apply to men remains unknown. Future studies should therefore recruit mixed-sex cohorts with adequate statistical power to examine whether the sleep–skin and stress–skin relationships identified in this dataset are reproduced, attenuated, or modified in male participants, a necessary step toward drawing population-level conclusions.

The association between poor sleep quality and self-reported scalp sensitivity (OR=1.17, Adj-P=0.004) warrants specific mechanistic consideration. This is consistent with existing knowledge of the skin-brain axis, where sleep-related HPA axis dysregulation can trigger neurogenic inflammation and compromise epidermal barrier function.[55] The higher frequency of immune-related complaints (sore throat, cold intolerance, frequent colds) among participants with poorer sleep quality suggests a potential link through systemic low-grade inflammation, a reported consequence of sleep insufficiency mediated in part through elevated pro-inflammatory cytokines including IL-6 or TNFα,[56,57] which may also contribute to the local manifestation of scalp neurogenic inflammation through neuroimmune crosstalk. Taken together, the associations identified across scalp sensitivity, skin fatigue appearance, and hair-related outcomes suggest that sleep quality and perceived stress are not peripheral considerations in dermatological practice. Routine enquiry into these domains may serve as a low-cost adjunct during consultations for patients presenting with scalp sensitivity, unexplained hair loss, or skin fatigue-related concerns, particularly in younger urban populations where chronic sleep impairment is prevalent yet underreported. This connection between systemic inflammatory status and scalp health warrants further investigation, including mechanistic studies linking lifestyle stressors to scalp neuroinflammation and cutaneous barrier dysfunction, and replication across diverse populations and settings.

Conclusion

In this cross-sectional observational study conducted in a healthy, general urban Chinese women aged 18–40 years, representative of real-life sleep and stress condition rather than acute deprivation or clinical disease setting, poor sleep quality and elevated perceived stress were associated with a range of dermatological concerns across skin, scalp and hair

outcomes. The findings confirm previously reported associations between sleep disturbance and facial skin appearance, and extend existing evidence by identifying the scalp as a particularly sensitive target of habitual poor sleep, with the most statistically robust association observed for self-reported sensitive scalp, an outcome that has received comparatively little attention in prior population-based research. The observation for clinically graded dark eye circle severity further illustrates that chronic, real-world sleep disturbance produces subtler dermatological changes than acute deprivation studies might suggest. Post-hoc exploratory age-stratified analyses suggested that associations with acne and skin elasticity may be most apparent in younger participants, though these findings require independent replication. Further research should prioritize longitudinal studies, mechanistic investigation of the sleep and stress related neuroinflammation pathway, and replication across diverse populations and settings.

Data Sharing Statement

The data supporting this study's findings are available upon reasonable request from the corresponding author (*Jie QIU;* janney.qiu@loreal.com).

Ethics Approval and Informed Consent

This study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol, all questionnaires, and consent procedures were reviewed and approved by the Ethics Committee of Ruijin Hospital on December 21, 2023 (Approval No. (2023) Lin-Lun-Shen-Di (347)). All participants provided written informed consent prior to their inclusion in the study, after receiving a full explanation of the study's purpose, procedures, potential risks, and benefits.

Acknowledgments

Sincerely thanks to AGUILAR Luc, BARBARAT Philippe, JAMMAYRAC Odette, SEYDI Mbinkindi, AZOUAOUI Anissa, DAL BELO Susi, DIRIDOLLOU Stephane, OTT Alban, BASTIEN Philippe, BODAS Cristina, GARCES Silvia (L'Oreal Research and Innovation, France), GUO Yuanying (L'Oreal Research and Innovation, China), Pr. CHEN Saijuan, Pr. LI Xia, Pr. CAO Hua, ZHU Zicong, SUN Yan (Ruijin hospital, Shanghai, China) for their great support of this work.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This study did not receive external grant funding. The study was conducted using instruments, questionnaires, and personnel time provided by L'Oréal Research and Innovation. This institutional support constitutes in-kind funding and is declared accordingly.

Disclosure

Several authors are employees of L'Oréal Group (Ping WANG, Juan LIU, Peggy SEXTIUS, Nathalie DESHAYES, Chengda YE, Frederic FLAMENT, Stephanie NOUVEAU, Jun WU, Xingyuan WANG, Zeneng SUN, Yu GAO, Emmanuelle MAINGUENE, and Jie QIU), which manufactures and markets cosmetic products for skin, scalp, and hair. This employment relationship represents a potential competing interest. The remaining authors (Shanqing WANG, Lihong CHEN, and Meng PAN) report no competing interests in this work.

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