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Artificial Intelligence-Driven Skin Aging Simulation as a Novel Skin Cancer Prevention

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Keywords
Skin cancer · Prevention · Skin aging · Simulation · Artificial intelligence

Abstract
Introduction: Skin cancer, a prevalent cancer type among fair-skinned patients globally, poses a relevant public health concern due to rising incidence rates. Ultraviolet (UV) radiation poses a major risk factor for skin cancer. However, intentional tanning associated with sunburns remains a common practice, notably among female adults. Appropriate prevention campaigns targeting children and adolescents are needed to improve sun protection behavior particularly in these age groups. The aim of our study was to investigate if an AI-based simulation of facial skin aging can enhance sun protection behavior in female adults. ***Methods:*** In this single-center, prospective, observational pilot study at Department of Dermatology at the University Hospital of Basel, we took photographs of healthy young females' faces with a VISIA-CR camera (Version 8.2; Canfield Scientific Inc., Parsippany, NJ, USA) between February and March 2021. Digital images were performed in three angles (straight, left 45°, and right 45°). All participants received an AI-based simulation of their facial skin with continuous aging to 80 years. A newly created anonymous questionnaire capturing participants' sociodemographic data and also tanning and sun protection behavior was completed in pre- and post-aging simulation. To observe long-term effects, a 2-year follow-up was conducted between March and April 2023. ***Results:*** The 60 participants (mean age 23.6 ± 2.5 years) evaluated the importance of sun protection significantly higher after skin aging simulation with VISIA-CR camera ($p < 0.0001$; 95% CI: 8.2–8.8). Post-intervention, 91.7% (55/60) of the females were motivated to reduce UV exposure and to intensify UV protection in the future since the individual UV-dependent risk was perceived significantly higher ($p < 0.001$; 95% CI: 5.9–6.7). At 2-year follow-up, 96% (24/25) indicated persistent effort reducing UV exposure. The preference for SPF 50+ sunscreen increased to 46.7% (28/65) directly after the skin aging simulation and continued to rise up to 60.0% (15/25) after 2 years. ***Conclusions:*** Our data emphasize the potential of AI-assisted photoaging interventions to enhance motivation for UV protection in the short and the long term. We encourage that different age and gender groups are addressed in a personalized, generation-

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specific manner with the appropriate media and by considering the Hawthorne effect. Campaigns with visual AI support can improve the intent of cancer-preventative behavior.

Introduction

Despite public education campaigns about the carcinogenic health dangers of ultraviolet (UV) exposure, tanning remains very popular [1]. In 2012, the World Health Organization (WHO) stated that UV radiation (UVR) is carcinogenic and can impact human health in several negative ways, e.g., causing cataracts and immune system damage [2]. Particularly, extensive UV exposure during childhood is seen to be the most modifiable risk factor for skin cancer [3, 4]. The personal amount of UV exposition mainly depends on strength of solar radiation, time spent outdoors during peak hours, and the management of UV protection (e.g., UV-protective clothing, sunscreen).

Sunlight tanning – defined as intentional outdoor tanning (OT) – and UV-induced indoor tanning (IT) are common behaviors, particularly among young adults [5]. In young adulthood, increasing UV exposure often starts because of the belief that tanning raises attractiveness [6, 7]. According to a US online survey, young women tended to engage in deliberate intentional OT resulting in an increased risk for skin cancer [8].

Skin cancer represents the most common cancer in the Caucasian population worldwide, and its incidence is on the rise [9, 10], posing a significant health and economic burden [10]. Damaging effects of UVR are thought to be caused by changes in immunologic function and direct cellular damage [11]. About 90% of melanomas are related to UV exposure, particularly the frequency of severe sunburns in childhood [12]. Thus, melanoma has even become one of the most common cancers among 25- to 29-year-olds [13]. Young, non-Hispanic white females represent the population most likely to use IT facilities. This population may be at high risk of skin cancer as recent meta-analyses support a strong association between cutaneous malignancy and IT. Changing tanning behavior and minimizing exposition to UVR in young adults are the most valuable strategies for skin cancer prevention [14]. Individual sun-protective measurements seem to be simple to implement, but awareness in broad parts of the population is not yet sufficient. A modeling study based on epidemiological data reported that an appropriate sun protection behavior in childhood may reduce the incidence of nonmelanoma skin cancer by almost 80% [15].

One of the most debated innovations in modern technologies and its impact on healthcare is artificial intelligence (AI). In medicine, this technology seems to have the potential of leading to better patient care. Due to its visual nature, dermatology is considered especially suitable for the use of AI [14]. Despite these opportunities, real-world clinical validation of different modern technology strategies in skin cancer prevention is currently lacking.

We hypothesize that age-appropriate prevention campaigns with AI support targeting young age groups may improve sun protection behavior. The aim of this study was to investigate the impact of AI-based simulation of facial skin aging on the attitudes toward skin cancer prevention among healthy young female volunteers.

Materials and Methods

Study Participants, Study Design, and Procedures

This single-center, prospective, observational pilot study among healthy young volunteers was performed at the Department of Dermatology at the University Hospital of Basel between February 2021 and May 2023. Participants were recruited at the University of Basel via study flyers. These flyers provided information about the study and its objectives. As young non-Hispanic white females represent a high-risk group for skin cancer, we confined our data collection to this subpopulation.

The inclusion criteria were female gender and age ≥18. Contact details (email and phone number) were obtained from all participants with their consent. Subsequently, each participant was assigned an individual patient ID, facilitating anonymization of the data.

All participants completed a newly created electronic questionnaire at baseline. Afterward, photographs of the volunteers' cleansed faces were taken with VISIA-CR camera (Version Visiav81-v8.2.02019-0705a; Canfield Scientific Inc., Parsippany, NJ, USA) using "standard mode" and "UV mode." Photos were made in three angles (straight, left 45°, and right 45°). Skin aging was shown continuously to the age of 80 years (shown in Fig. 1). Post-intervention, participants completed a second electronic questionnaire. A 2-year follow-up encouraging participants to complete post-intervention questionnaire again was conducted between March and May 2023. For the 2-year follow-up, participants were initially contacted via email. If they did not respond within the specified deadline of 2 weeks, they were also contacted by phone to maximize the response rate.

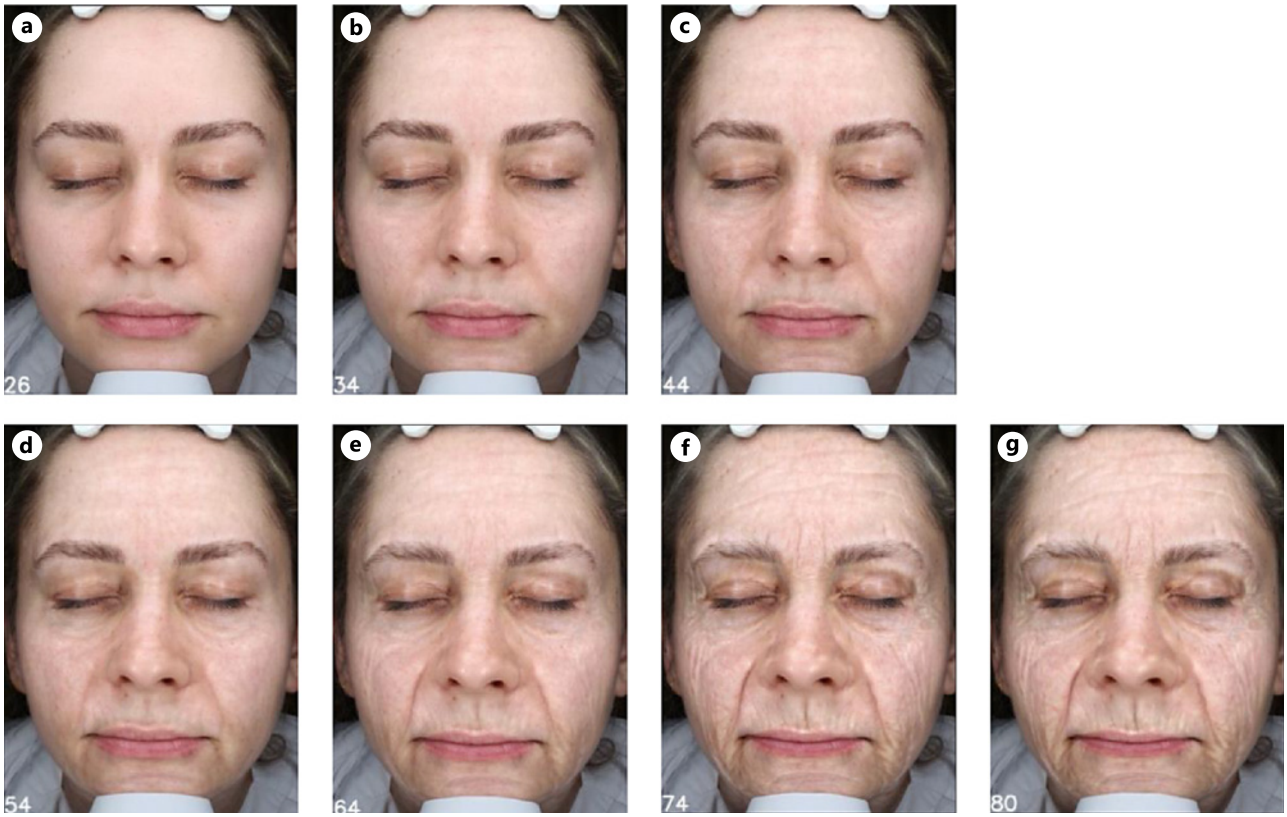

Fig. 1. Skin aging simulation by VISIA-CR camera. **a–g** Images of a 26-year-old participant in whom simulation of facial skin aging was conducted. Simulated age is indicated in the lower left-hand corner of each image.

Questionnaire

All participants completed a newly created digital 20-item questionnaire with their smartphone (shown in online suppl. Fig. 1; for all online suppl. material, see https://doi.org/10.1159/000541943). Each participant was assigned a patient ID, which was evident on the questionnaire. Data collection was performed twice pre- and post-skin aging simulation. The questionnaire addressed demographic and educational participant data. Additionally, participants were asked to assess their individual risk regarding UV exposure pre- and post-skin aging simulation. Volunteers' tanning behavior and their motivation for intentional UV exposure were investigated. Furthermore, attitudes toward sunscreen and participants' application pattern were explored, e.g., preferred sun protection factor (SPF), number of fingertip units used, sunscreen application frequency, barriers for using sunscreen. Self-reported importance of sunscreen pre- and post-intervention was studied. The questionnaire contained binary questions (yes/no) and multiple-choice questions. The individual risk regarding UVR and importance of sunscreen were self-reported on 10-point Likert scales for quantitative evaluation. The Hawthorne effect refers to the phenomenon where individuals modify their behavior or performance in response to being observed or studied. This effect suggests that people may change their behavior simply because they are aware of being studied, rather than in response to any specific intervention or treatment being tested. We attempted to address this effect as well as social desirability bias by implementing complete anonymization of our questionnaire.

Statistical Analysis

We performed descriptive analysis using SPSS 28 (IBM Corporation, Armonk, NY, USA) and Microsoft Excel. Significant associations and correlations among parameters were detected using χ^2 tests (phi φ) and Fisher's exact test if expected frequency in any cell was <5. Comparisons between multiple groups were made using single-factor ANOVA, paired *t* test for paired variables, and 2 sample *t* tests for independent variables. For all analyses, a *p* value of <0.05 was defined as being significant.

Results

A total of 60 female volunteers (mean age 23.6 ± 2.5 years; 90.0% [54/60] medical students) participated in this study (shown in Table 1), and overall 41.6% (25/60) participants responded the follow-up. Reasons for the participant's dropout were the lack of accessibility or missing feedback via phone and email.

All respondents (100%, 60/60) have intentionally sought OT once before the study participation. Only one female (1.7%, 1/60) indicated use of artificial IT devices. Sunscreen with an SPF of 30–50 was used most frequently (61.7%, 37/60). About 13.3% (8/60) of participants stated to intentionally expose themselves to UVR for a prolonged period without using any sun protection.

Alterations of UV Protection Pre- and Post-Skin Aging Simulation and at 2-Year Follow-Up

To 68.3% (41/60) of our participants, UV exposure has become less attractive after skin aging simulation with VISIA-CR camera. We observed no significant differences between the different cohorts of medical students versus other professions ($p = 0.28$, phi = −0.107) and respondents at self-reported "very high risk" due to UV exposure (very high risk = 10 on a 10-point Likert scale post-simulation; $p = 0.35$, phi = −0.011). Most respondents (91.7%; 55/60) stated the intention to reduce their UV exposition and to use more intensive sun protection (e.g., UV-protective clothing, application of higher SPF sunscreen) after the intervention (Table 1). No differences existed between the subgroups of professions and volunteers at self-reported "very high risk" due to UV exposure in willingness to intensify future sun protection post-intervention ($p = 0.58$, phi = 0.102).

At 2-year follow-up, 76.0% (19/25) of participants stated that UV exposure has become less attractive to them with 96.0% (24/25) of respondents indicating the persistent effort to reduce UV exposition. After the skin aging simulation with VISIA-CR camera, volunteers rated the importance of sun protection significantly higher ($p < 0.0001$; 95% CI: 8.2–8.8). In the 2-year follow-up, a trend in this regard is still noticeable ($p = 0.2281$; 95% CI: 7.6–8.8). The self-reported importance of UV protection to our respondents was rated on a 10-point Likert scale pre- and post-skin aging simulation of facial skin aging such as at 2-year follow-up (shown in Fig. 2). We found variations among subgroups of medical students and other professions ($p = 0.0014$; 95% CI: 8.2–8.8). Scheffé post hoc test revealed a higher importance of sunscreen in medical students' post-skin aging intervention compared to participants with other professions (Table 2).

Most participants (61.7%, 37/60) reported using SPF 30–50 sunscreen prior skin aging simulation which reduced to 51.7% (31/60) preference for SPF 30–50 sunscreen after skin aging simulation, observing a significant increase among all participants in the use of SPF 50+ after the intervention ($p = 0.0096$, phi = −0.171). This effect persisted even 2 years post-simulation ($p < 0.001$, phi = −0.280; shown in Fig. 3). While an SPF of 50+ was favored by 30.0% (18/60) of respondents' pre-simulation, the preference for SPF 50+ sunscreen use increased to 46.7% (28/60) after the skin aging simulation and to 60.0% (15/25) at the 2-year follow-up.

Individual Risk due to UV Exposure

Skin cancer caused by UV exposure was rated by all study respondents as a relevant health risk (100%, 60/60). Other negative aspects of UVR such as sunburn (98.3%, 59/60), accelerated skin aging (85.0%, 51/60), and ophthalmological damages (e.g., cataract, macular degeneration) (68.3%, 41/60) seemed also to be relevant to the great majority of participants.

Respondents were asked to estimate their individual risk related to UVR on a 10-point Likert scale, pre- and second time post-skin aging simulation, where number 1 represents "no risk" and number 10 represents "very high risk" (shown in Fig. 4). The individual risk to UV exposure was perceived significantly higher shortly after simulation just as at 2-year follow-up ($p < 0.001$; 95% CI: 5.9–6.7; $p < 0.01$; 95% CI: 5.7–6.6). No differences were observed among different subgroups ($p = 0.16$; 95% CI: 5.9–6.7; Table 3).

Self-reported high risk regarding UVR (levels of >6 on 10-point Likert scale) did not correlate with using a high SPF sunscreen (SPF 50+) before skin aging simulation ($p = 0.12$; 95% CI: 5.4–6.4). Post-skin aging simulation, self-estimated higher risk levels due to UVR were associated with the intention of future use of SPF 50+ sunscreen ($p = 0.002$; 95% CI: 6.2–7.2; Table 4).

Participants' Motivations for Intentional UV Exposure

Raising mood seemed to be the most common motivation for intentional UV exposure pre- and post-intervention with 34.3% (49/60) versus 35.7% (47/60)

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Table 1. Characteristics of the study population and their tanning behavior

Characteristics	Patients pre-skin aging simulation, % (*n*) (*n* = 60)	Patients post-skin aging simulation, % (*n*) (*n* = 60)
Gender		
Females	100% (60)	
Profession		
Medical student	90.0% (54)	
Other profession	10.0% (6)	
Exposure to UVR		NA
Outdoor	100% (60)	
Indoor (sunbed)	1.7% (1)	
Application frequency of sunscreen		NA
No use	0% (0)	
<10 days per year	5.0% (3)	
10–20 days per year	18.3% (11)	
>20 days per year	76.7% (46)	
Not specified	0% (0)	
FTUs used per application (face)		NA
≤1 FTU	16.7% (10)	
2 FTUs	46.7% (28)	
3 FTUs	23.3% (14)	
4 FTUs	8.3% (5)	
5 FTUs	5.0% (3)	
≥6 FTUs	0% (0)	
UV exposure without using sunscreen		NA
Yes	13.3% (8)	
No	86.7% (52)	
Product-based parameters for not using sunscreen (multiple answer options)		NA
Shiny looking/greasiness	40.0% (24)	
White appearance on skin	48.3% (29)	
Soiling of clothing	43.3% (26)	
Adhesive residues on palms	53.3% (32)	
Concern about noxious ingredients	23.3% (14)	
Concern about intolerances	16.7% (10)	
Not specified	8.3% (5)	
External parameters for not using sunscreen (multiple answer options)		NA
No sunscreen available	78.3% (47)	
Financial reasons	1.7% (1)	
Practical reasons (lack of time)	30.0% (18)	
Occupational reasons (working outdoors, lack of time)	5.0% (3)	
Not specified	16.7% (10)	
Known damaging effects of UV exposure		NA
Sunburn	98.3% (59)	
Accelerated aging of skin (e.g., wrinkles, senile lentigo)	85.0% (51)	
Skin cancer	100% (60)	
Eye damage (e.g., macular degeneration, cataract)	68.3% (41)	
Intention to intensify sun protection behavior	NA	
Yes		91.7% (55)
No		8.3% (5)

FTU, fingertip unit.

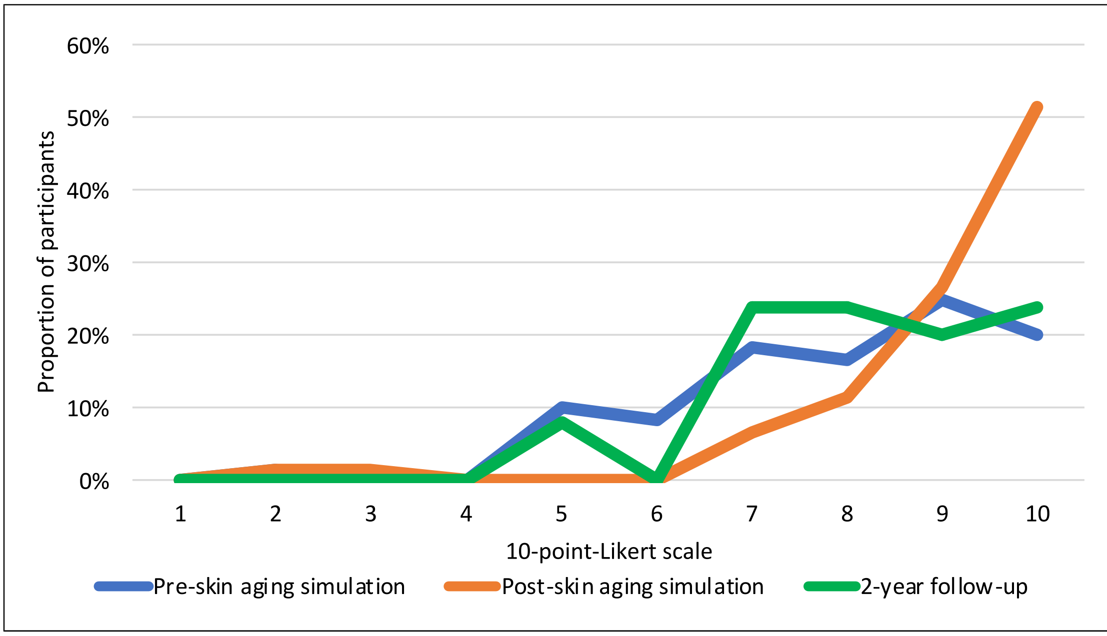

Fig. 2. Importance of UV protection rated on a 10-point Likert scale (1 = least important; 10 = most important), pre- and post-skin aging simulation and at 2-year follow-up.

Table 2. Significance of sunscreen among different cohorts pre- and post-skin aging simulation by VISIA-CR camera

Rating on 10-point Likert scale	Medical student (*n* = 54), % (*n*)	Other profession (*n* = 6), % (*n*)	*p* value
Pre-skin aging simulation			
1 (least/not important)	0% (0)	0% (0)	0.0014
2	1.6% (1)	0% (0)	
3	0% (0)	0% (0)	
4	0% (0)	0% (0)	
5	9.3% (5)	16.6% (1)	
6	7.4% (4)	16.6% (1)	
7	20.4% (11)	16.6% (1)	
8	16.6% (9)	16.6% (1)	
9	25.9% (14)	16.6% (1)	
10 (very important)	18.5% (10)	33.3% (2)	
Post-skin aging simulation			
1 (least/not important)	0% (0)	0% (0)	
2	1.6% (1)	0% (0)	
3	0% (0)	16.6% (1)	
4	0% (0)	0% (0)	
5	0% (0)	0% (0)	
6	0% (0)	0% (0)	
7	7.4% (4)	0% (0)	
8	9.3% (5)	33.3% (2)	
9	29.6% (16)	0% (0)	
10 (most important)	51.9% (28)	50.0% (3)	

as well as at 2-year follow-up with 30.6% (19/25). Before being exposed to the aging simulation, increased vitamin D synthesis caused by prolonged UV exposure was a motivation to tan for 24.5% (35/60), afterward for 28.8% (38/60), and after 2 years for 25.8% (16/25). Prior to the simulation of facial skin aging, raising attractiveness by

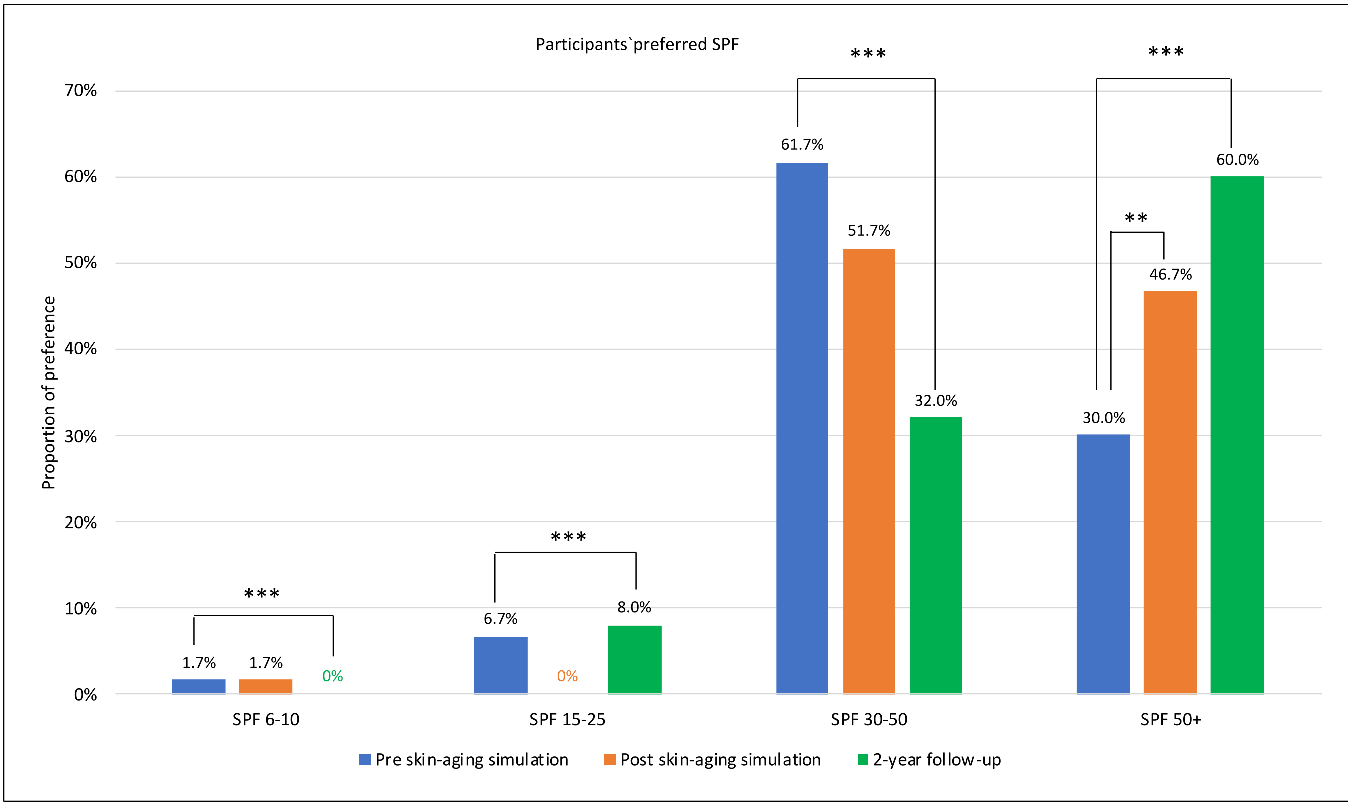

Fig. 3. Participants' preferred SPF pre- and post-skin aging simulation and at 2-year follow-up by VISIA-CR camera; $^{**}p$ < 0.01; $^{***}p$ < 0.001.

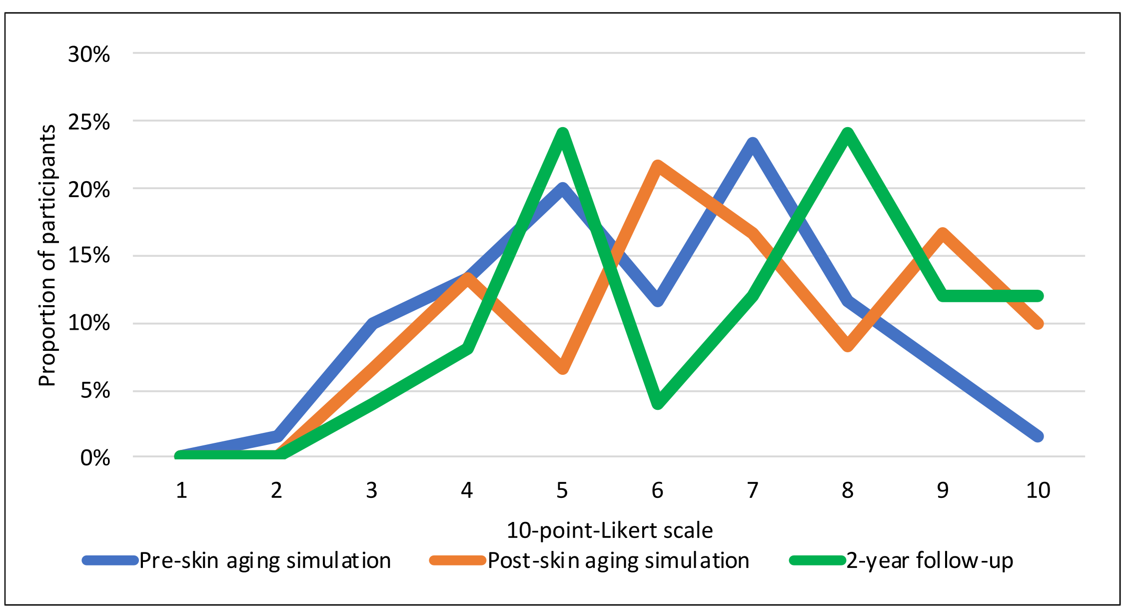

Fig. 4. Individual risk due to UVR rated on a 10-point Likert scale (1 = no risk; 10 = very high risk), pre- and post-skin aging simulation and at 2-year follow-up.

Table 3. Individual risk due to UVR among different cohorts pre- and post-skin aging simulation by VISIA-CR camera

Rating on 10-point Likert scale	Medical student (n = 54), % (n)	Other profession (n = 6), % (n)	p value
Post-skin aging simulation			
1 (low/no risk)	0% (0)	0% (0)	0.16
2	1.6% (1)	0% (0)	
3	7.4% (4)	33.3% (2)	
4	14.8% (8)	0% (0)	
5	20.4% (11)	16.6% (1)	
6	11.1% (6)	16.6% (1)	
7	24.1% (13)	16.6% (1)	
8	13.0% (7)	0% (0)	
9	5.5% (3)	16.6% (1)	
10 (very high risk)	1.6% (1)	0% (0)	
Post-skin aging simulation			
1 (low/no risk)	0% (0)	0% (0)	
2	0% (0)	0% (0)	
3	7.4% (4)	0% (0)	
4	13.0% (7)	16.6% (1)	
5	7.4% (4)	0% (0)	
6	22.2% (12)	16.6% (1)	
7	14.8% (8)	33.3% (2)	
8	7.4% (4)	16.6% (1)	
9	18.5% (10)	0% (0)	
10 (very high risk)	9.3% (5)	16.6% (1)	

skin tanning was a reason to tan for 23.1% of the participants (33/60) compared to only 9.8% (13/60) after the intervention. This factor has increased after 2 years to 16.1% (10/25). Before the aging simulation, only 1.4% of participants indicated that they had no motivation for intentional UV exposure; afterward, that fraction increased to 5.3% (7/60) (Fig. 5).

Discussion

Our study highlights that the implementation of computer-based skin aging simulation in healthcare settings contributes to improve young adults' attitudes toward skin cancer prevention in the short and also long term.

Prevalence of Sun-Protective Behavior and Intentional OT

We observed that all female participants had been intentionally seeking OT before the study participation. However, nearly 15% of our volunteers intentionally tanned outdoors without using sunscreen, which is in line with previous studies [15, 16]. In 2018, a US study among intentional tanning behavior demonstrated that females are more likely to engage in intentional OT than males [8]. However, a recent study investigating intentional tanning behavior in Germany found a higher likelihood for intentional OT among men [16]. Overall, intentional tanning behavior seems to affect both sexes as well as all skin types [16]. Therefore, future effort to reduce intentional tanning behavior should address the general population.

Using sunscreen is a very common measure to protect against sunburn in our cohort which supports prevention behavior in Wales that demonstrated females being more likely to use sunscreen (>80%) compared to males [17]. Fighting against the increasing incidence of skin cancer worldwide and raising awareness in the public, various health programs have been implemented in the last years. In Australia, the continent with the highest incidence of skin cancer, several skin cancer prevention campaigns were realized with the most prominent measure of banning sunbed use in 2016 [14]. Among younger cohorts stabilizing or declining incidence rates of melanoma in Australia have been observed potentially caused by these primary prevention campaigns aimed at reducing UV exposure. In contrast, incidence rates of melanoma are still on the rise in most European countries and in the USA [18], displaying the need for implementation of more effective prevention measures.

Table 4. Willingness to use sunscreen with SPF 50+ and correlation with self-reported risk due to UVR pre- and post-skin aging simulation with VISIA-CR camera (n = 60)

Rating on 10-point Likert scale	Total, % (n)	SPF 50+, % (n)	SPF <50+, % (n)	p value
Pre-skin aging simulation				
1 (low/no risk)	0% (0)	0% (0)	0% (0)	0.12
2	1.7% (1)	1.7% (1)	0% (0)	
3	10.0% (6)	5.0% (3)	5.0% (3)	
4	13.3% (8)	1.7% (1)	11.6% (7)	
5	20.0% (12)	3.3% (2)	16.6% (10)	
6	11.6% (7)	0% (0)	11.6% (7)	
7	23.3% (14)	6.6% (4)	16.6% (10)	
8	11.6% (7)	5.0% (3)	6.6% (4)	
9	6.6 (4)	5.0% (3)	1.7% (1)	
10 (very high risk)	1.7% (1)	1.7% (1)	0% (0)	
Post-skin aging simulation				
1 (low/no risk)	0% (0)	0% (0)	0% (0)	0.002
2	0% (0)	0% (0)	0% (0)	
3	6.6% (4)	1.7% (1)	5.0% (3)	
4	13.3% (8)	3.3% (2)	10.0% (6)	
5	6.6% (4)	1.7% (1)	5.0% (3)	
6	21.6% (13)	11.6% (7)	10.0% (6)	
7	16.6% (10)	5.0% (3)	11.6% (7)	
8	8.3% (5)	1.7% (1)	6.6% (4)	
9	16.6% (10)	11.6% (7)	5.0% (3)	
10 (very high risk)	10.0% (6)	10.0% (6)	0% (0)	

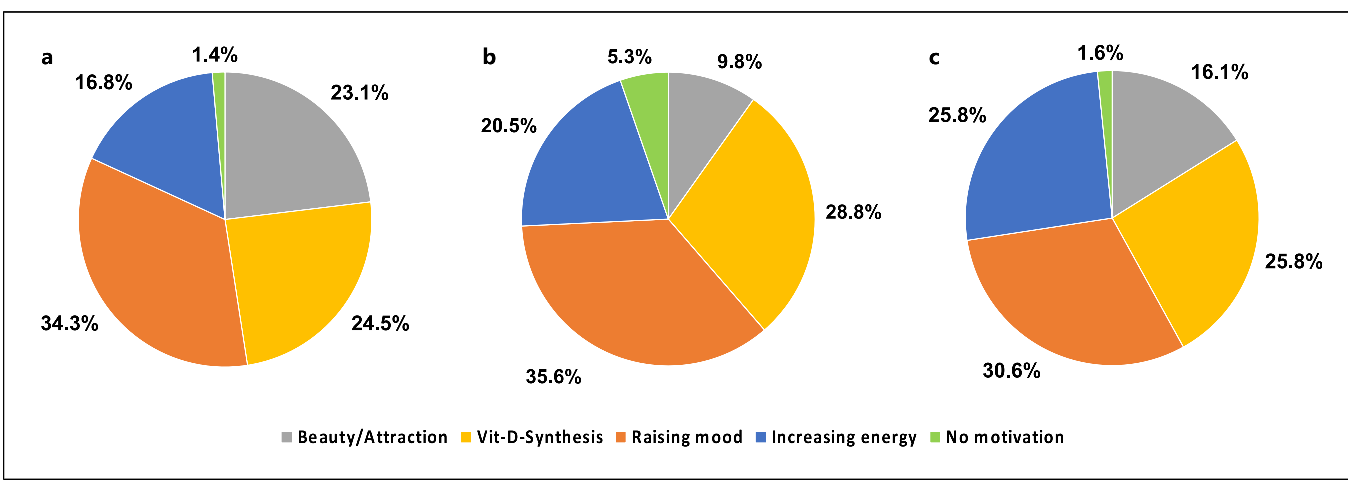

Fig. 5. a Participants' motivation for intentional UV exposure pre-skin aging simulation with VISIA-CR camera. **b** Participants' motivation for intentional UV exposure post-skin aging simulation with VISIA-CR camera. **c** Participants' motivation for intentional UV exposure at 2-year follow-up. Multiple answers were possible.

Health and Economic Burden of IT

In comparison with previous studies, the prevalence of IT in our study population seems to be quite low even though there is no national ban on IT, as it exists in Brazil or Iran [1]. Skin cancer incidence has risen significantly particularly in young female adults due to increasing use of recreational tanning and the perceived social desirability of tanned skin. People using sunbed increase their risk of melanoma by almost 60% and for squamous cell carcinoma by 67% [19, 20]. Consequently, in 2009 IT devices were classified as carcinogenic by the WHO's International Agency for Research on Cancer [21].

Skin cancer is not only a major public health concern but has also an enormous economic burden. A modeling study analyzing individuals 12–35 years old in North America and Europe commonly engaging in IT indicated that with a ban on IT devices cost savings of USD 31.1 billion in North America and USD 15.9 in Europe could occur [22, 23]. A British cost-effectiveness analysis emphasizes that banning commercial IT combined with a public information campaign would result in 1,206 avoided cases of melanoma, 207 fewer averted deaths from melanoma, and 3,987 fewer cases of keratinocyte cancer being preventable over the lifetime of all 18-year-olds [20]. Additionally, the authors also provided evidence that implementing a ban on IT in England would save healthcare costs. We suggest public health campaigns and nationwide sunbed bans to go hand in hand with AI-based interventions for skin cancer prevention in adolescents and young adults.

Application Pattern and Changes of Participants' Sunscreen Preferences

Right before aging simulation, most of our participants reported preferring SPF 30–50 sunscreen. At 2-year follow-up, most of our respondents indicated favoring SPF 50+. Similar to our data, a study investigating knowledge and attitude of general population toward sunscreens with SPF 30–50 was used most frequently. However, in contrast to our population where all individuals perceived skin cancer as a significant risk of UVR, only 43% of respondents thought that sun exposure can cause skin cancer. This disparity is likely because our sample consists of individuals with relatively high level of education with 90% medical students. Knowledge about UV-induced skin damage and its consequences, such as skin cancer, seems not yet widely disseminated in the general population. Therefore, we perceive a need for more prevention and awareness campaigns.

To be effective, sunscreen must be applied in a sufficient quantity and should be replicated. According to the guidelines from the American Food and Drug Administration [24], the amount of sunscreen should be 2 mg/cm^2 reflecting the standardized amount when labeling SPF and according to Euromelanoma campaign SPF 50+ sunscreen is recommended [25]. Real-world data demonstrated that individuals often apply less, just 0.39 and 0.79 mg/cm^2 which results in a more limited UV protection than expected [26], confirming our data, that our population frequently underdosed sunscreen at baseline. The current labeling of sunscreens appears to overestimate the protective efficacy, which may mislead consumers into feeling safe and exposing themselves to the sun for longer periods of time.

Our findings indicate that there is a long-term effect using AI-assisted skin aging simulation on sun protection behavior. Thus, we illustrated that the number of individuals willing to use SPF 50+ sunscreens after the intervention increases in the short and also long term. In contrast to our study addressing primary prevention using an AI, most available studies focus on AI-assisted secondary prevention and diagnosis, respectively. The advances in visual recognition AI make application and integration of the technology particularly suited for perceptual specialties such as dermatology. In dermatology, AI is poised to improve the efficiency and accuracy of traditional diagnostic approaches, including visual skin examination. Skin self-examination is an important secondary prevention strategy reducing melanoma deaths [27]. A literature review addressing the impact of interactive skin self-examination digital platforms for the prevention of skin cancer identified only one study among 32 included ones that showed an improvement in a skin self-examination outcome compared to the control group [28]. Future studies should aim to better assess the usability and functionality of AI such as digital health apps.

The most prevalent barrier to use sunscreen on a regular basis in our study was inconvenience (i.e., shiny looking), followed by soiling of clothing and sticky residues on the palms. Previous studies have shown need to reapply [29], as well as undesirable smell of sunscreen [30] and perceived lack of need [31] to be frequent barriers. In a modeling study calculating the potential effects of school-aged UV protection intervention, the cumulative melanoma incidence 70 years after the intervention would decline by approximately 20% if all adolescents started using sunscreen regularly [32]. Our data give valuable implications for future skin cancer prevention strategies and the sunscreen industry. In our study, the beauty aspect remained one of the main reasons for motivational tanning after 2 years. This contrasts with the increasing willingness to use SPF 50 sunscreen in the long term. Therefore, it is crucial to develop more product innovations addressing concerns of inconvenience such as doing more preventive work highlighting the importance of adequate sun protection in the future.

Skin Cancer Awareness and AI

Following the aging simulation with VISIA-CR camera, 70% of the participants expressed a decrease in the attractiveness of UV exposure and 90% intended to intensify UV protection behavior in the future. Moreover, the importance of UV protection was rated significantly higher after the simulation. Similarly, to our findings by investigating the effect of a facial aging mobile app on skin cancer protection behavior of adolescents, Brinker et al. [33] showed that daily sunscreen use increased at 6-month follow-up. A systematic review of 20 publications concerning appearance-based interventions indicated that they were successful in reducing UV exposure [34]. Somewhat against our expectations, respondents at self-reported "very high risk" regarding UVR were not more likely to implement prevention behavior (e.g., using SPF 50+ sunscreen) than those at self-reported "low risk" pre-simulation of facial aging. However, individuals with self-reported "very high risk" did reveal the intention of changing behavior in the future. A randomized controlled clinical trial examining long-term efficacies of exposure to photoaging information regarding sun protection behaviors in young adults reported appearance-based interventions to be a promising approach for primary prevention practices [35]. Negative health consequences of tanning occur in long term. In our study, intentional UV exposure was often linked with positive emotions like *increasing mood* and *increasing vitamin D synthesis*. After aging simulation, motivation for UV exposure decreased significantly. Especially young adults might find it difficult to visualize distant future and focus on current perceived cosmetic benefits [36]. In 2014, a randomized trial with Australian high school students demonstrated that appearance-based videos on UV-induced premature aging were superior in encouraging sunscreen use to videos focusing exclusively on health aspects [37]. In a pilot study among Brazilian adolescents, investigating success of a photoaging intervention for skin cancer prevention revealed that after the intervention more than 90% of the participants were motivated to reduce UV exposure [12]. Our findings are in accordance with studies in young adults which concluded that appearance-based interventions were more effective than classic health education programs [37, 38]. Skin aging simulation using AI demonstrated a long-lasting impact on sun protection behavior in young female adults. Accordingly, 96% of participants indicated that the intervention had a persisting effect on their UV exposure. Especially in North America and Europe, skin cancer is an immense economic burden [23]. In order to reduce healthcare costs associated with the diagnosis and treatment of skin cancer, a brief intervention with AI bears enormous potential. Consequently, Areia et al. [39] showed that implementation of AI detection tools in colorectal cancer screening is a cost-saving strategy to further prevent cancer incidence and mortality. To be clinically useful, AI must be integrated into the daily routine and clinical workflow of a dermatologist. We are convinced that AI has the potential being a cost- and time-saving tool in clinical practice.

Strengths and Limitations

Strengths of the present study are a prospective study design in one of European countries with the highest incidence of skin cancer and the validation of a new AI-assisted skin aging simulation for skin cancer prevention. However, the study also has some limitations, including a small sample size, single-center setting, the lack of a control group, self-reported outcomes only, and the possible selection bias of the participants. Therefore, a generalization of our results should be considered with caution. Another limitation of our study is that when asking about the preferred SPF and the frequency of sunscreen application, differentiation between the face and the rest of the body was not discerned. The images depicting skin aging only simulate intrinsic aging. This may be misleading for the individuals participating. A comparative presentation of skin aging under the conditions of sun exposure and skin aging under the application of sun protection measures was not possible due to the lack of a skin aging simulation algorithm, but the consideration of extrinsic skin aging would be recommended for future studies.

Subgroup analysis was not conducted at 2-year follow-up due to the small sample size. The follow-up results might be biased by the Hawthorne effect since participants were contacted via email or phone. Additionally, the study contains of subjective questionnaire-based patient-reported outcome measures; thus, objective comparisons are lacking. The feasibility of the VISIA-CR camera aging simulation is currently not available for everyday use. Further studies with a broader patient population considering the Hawthorne effect validating a corresponding app with these AI-based simulations are needed.

Conclusion

Our data highlight that AI-assisted prevention campaigns with skin aging simulation have the potential to improve skin cancer awareness and thus primary prevention of skin cancer in young female adults and adolescents in the long term. Importance of UV protection was rated significantly higher after the simulation, and almost all our participants intended to intensify their future UV protection behavior. The AI-driven skin aging simulation revealed even long-lasting effects on sun protection behavior in the 2-year follow-up. We propose to conduct personalized, age-appropriate appearance-focused skin cancer prevention campaigns with AI support to rise motivation for UV protection.

Key Message

By awareness improvement through AI-assisted photoaging interventions, we highlight its potential for skin cancer prevention.

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Statement of Ethics

The study was approved by the Northwest and Central Switzerland Ethics Committee (BASEC-Number 2020-00963) and was registered with ClinicalTrials.gov (NCT04532437). The study was performed in full accordance with the Declaration of Helsinki (1964), and Good Clinical Practice was maintained throughout the study. Written informed consent to participate in the study as well as written informed consent to use the photos was obtained from the participants at the beginning of the study.

Conflict of Interest Statement

L.G. and S.E.C. declared no conflict of interest. J.-T.M. has served as advisor and/or received speaking fees and/or participated in clinical trials sponsored by AbbVie, Almirall, Amgen, BMS, Celgene, Eli Lilly, LEO Pharma, Janssen-Cilag, MSD, Novartis, Pfizer, Pierre Fabre, Roche, Sanofi, and UCB. A.A.N. declares being a consultant and advisor and/or receiving speaking fees and/or grants and/or served as an investigator in clinical trials for AbbVie, Almirall, Amgen, BioMed, BMS, Boehringer Ingelheim, Celgene, Eli Lilly, Galderma, GSK, LEO Pharma, Janssen-Cilag, MSD, Novartis, Pfizer, Pierre Fabre Pharma, Regeneron, Sandoz, Sanofi, and UCB. L.V.M.-D. has served as advisor and/or received speaking fees and/or participated in clinical trials sponsored by Almirall, Amgen, Eli Lilly, Incyte, MSD, Novartis, Pierre Fabre, Roche, and Sanofi outside of the current work (fees to the institution).

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Author Contributions

L.V.M.-D. and S.E.C. conceived the study and were in charge of overall direction and planning. S.E.C. collected the data. L.G. conceived and designed the statistical analysis. L.G. and L.V.M.-D. wrote the manuscript with input from all authors. J.-T.M. led on planning and integrating gender-specific aspects. The project was supervised by L.V.M.-D. All authors provided critical feedback. A.A.N. shaped the research, analysis, and manuscript.

Data Availability Statement

All data generated or analyzed during this study are included in this article and its online supplementary material files. Further inquiries can be directed to the corresponding author.

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