Intersection of cosmetic technology and wellness
~Utilizing skin research techniques for stress management

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Abstract

Background: Dealing with stress well is important for a better life. To this end, you must know how stressed you are so you can take preventative self-care actions. However, the wide variety of stress symptoms and dynamic fluctuations make this difficult. We thought that facial information can be used to solve this problem because the facial skin is affected by stress accumulation in various ways. In this research, we developed technologies to visualize the stress state using various information from the face, and we developed a mechanism to improve wellness/wellbeing based on the extracted data.

Methods: Machine learning technologies were utilized for this study. Stress data were defined considering autonomic state, blood markers, urine markers, subjective state, and quality of life. Models were created to evaluate these items using facial information (facial questionnaire, stratum corneum cell images, facial images, and facial videos). Furthermore, a smartphone application combining several of these analysis technologies with original digital content was developed and its usefulness was confirmed by individual users.

Results: We developed evaluation models for fifteen stress states with accuracy of >70.0%. During the verification results using the prototype, we observed not only improvements in positive mindset for self-care awareness and negative mood, reduction of fatigue states but also better skin conditions.

Conclusion: This study demonstrates two important points. (1) The possibility of a new way to utilize cosmetics technology in another field, wellness/wellbeing. (2) The possibility of new way to improve skin condition by stress management, “non-cosmetic skin care”.

Keywords: facial imaging; stratum corneum; smartphone; wellness; wellbeing; stress management

Introduction.

Recently, partially due to COVID19, wellness and wellbeing have become increasingly important parts of daily life. Additionally, the target of Sustainable Development Goal 3 (World Health Organization) is "GOOD HEALTH AND WELL-BEING", signifying that maintaining a healthy state is one of the most important themes in the world.

For that purpose, one major focus is stress management, since stress can manifest as physical or mental illness and have negative effects on not only performance and feelings but also skin conditions. The proper stress management is important, but it is difficult to do well. There are two issues, one is difficulty in recognizing the need for self-care and the other is the lack of proper self-care methods (easy for anyone to experience and feel effectiveness).

The first issue is the most important point, and is attributed to difficulty in knowing one's stress state. If people are aware of their own stress, it makes it easier for them to manage their own wellbeing through rest or mental self-care. However, it is difficult to know one's stress state, people don't recognize the need for self-care, so self-care actions are not taken. This can consequently cause a variety of illnesses. However, there are various types of stress symptoms (e.g. accumulation of mental and physical fatigue, stress markers in the blood, or changes in the autonomic nervous system), and the way they appear varies greatly depending on the individual, and some of these fluctuate dynamically (e.g. changes in the autonomic nervous system), hence it is difficult to know one's own stress state precisely. Therefore, a comprehensive, easy stress status monitoring technology is needed.

For dealing with this issue, we wanted to leverage the knowledge and experience of the beauty industry since there are many reports that suggest correlations between stress state or stress risk and facial/skin conditions. For example, it has been reported that chronic mental and physical stress accumulation changes the macro-morphology of the skin, such as the occurrence of wrinkles and the decrease in skin thickness [1]. Accumulation of psychological stress is known to be associated with exacerbation of skin diseases [2], decreased stratum corneum cell barrier function [3], and increased skin saccharifying substances [4]. As the *in vivo* mechanism, it has been suggested that mental stress enhances the production of glucocorticoids, resulting in a decrease in the barrier function of the stratum corneum [5]. In addition, in a report suggesting the relationship between stress state and skin, it has been reported that lack of sleep causes a decrease in the barrier function of the stratum corneum cells, a decrease in the resilience of the stratum corneum damage, and a decrease in the anti-inflammatory function [6, 7]. It has also been reported that lack of sleep causes changes in skin macro-morphology such as dark circles, wrinkles, and a drooping mouth [8]. From these things, we thought that there is a possibility that various states of stress can be inversely evaluated using the face and skin.

The second issue for proper stress management is that there is no universally known easy self-care method anyone can do. Commonly known ways to for stress management are through sensory experiences (listening to relax music, looking at beautiful images, smelling aromas, and focusing one's senses, such as mindfulness meditation). However, these methods require preparation, choices tailored to one's stress state, and have varying efficacy. Therefore, we decided to develop an individualized, easy to use, and effective sensory experience for one’s own condition. For dealing with this issue, we wanted to leverage the knowledge of the previous study that demonstrated individualized sensory experiences on skin (vibrations) can make humans relax. We found in previous studies that people feel more relaxed when they feel the vibrations through their skin that start at the same rate as the subject's heartbeat and slows. Based on this research, we created the original skin-centered stimulation program, and combined with the stress evaluation program, which allows self-care actions to be taken immediately after the analysis. We think that this system is ideal for self-care, because people are most likely to take action after knowing the analysis results.

In summary, the objective of this study is to construct a "skin-centered self-care system" that uses skin analysis as a starting point to learn about one's own stress condition, and to provide solutions through sensory stimulation via the skin. For that purpose (1) we focused on facial information as an indicator of stress and developed a unique stress state evaluation technique using deep learning technology. Then, (2) as a pilot study, we created a smartphone application prototype that combines some of our analytical technologies with our own digital solutions centered on vibration experience to test the importance of knowing yourself and the usefulness of daily self-care actions.

Our technology will allow people to easily and engagingly become aware of their stress and to take self-care actions more often before serious health problems occur.

Materials and Methods.

All studies were conducted after obtaining approval from the POLA Ethics Committee. And informed consents were obtained before the participant enters the research.

<u>1-1 Subject and collected data for developing stress state evaluation models</u>

Data were obtained from 2321 Japanese men and women from their 20s to 50s. The data collection period was from 2017 to 2021. Although the dataset differed according to the analyses, the maximum number of data were used at the time of each analysis. For facial information, we used four types of data commonly used in cosmetics research, which were subjective questionnaire, facial images, stratum corneum cell images, facial movie data. Subjective questionnaires were collected from the subjects, and facial photos and videos were taken with smartphone (iPhone 7) fixed to a pedestal. The stratum corneum cells were collected by tape stripping from right cheek region (2 cm x 2 cm area centered on the intersection of the line vertically down from the outer corner of the eye and from the alar base extended horizontally, and then stained with a mixture of gentian violet and brilliant green. The cell images were taken under microscope (150x).

Stress data were defined considering autonomic state, blood markers, urine markers, subjective state, and quality of life. The autonomic states were heart rate and heart rate variability (CVRR: coefficient of variation of R-R interval and LF/HF: the ratio of the low- and high-frequency bands in heart rate variability) [9, 10]. These data were collected by wearable heart rate sensors (myBeat, UNION TOOL CO.).

The blood markers were dROM (diacron reactive oxygen metabolites) [11], Oxidative Stress Index [12], the urine markers were isoprostane [13], 8-OHdG (8-OHdG;8-hydroxy-2’-deoxyguanosine)[14], vanillylmandelic acid[15], and homovanillic acid [16, 17]. They were analyzed using blood and urine samples collected from the subjects. The subjective state were Chalder fatigue scale [18], mental fatigue scale and physical fatigue scale [19]. The quality of life were the Athens Insomnia Scale [20], the Pittsburgh Sleep Quality Index [21], and the individual's frustrated feeling scored using a 10 point scale. They were collected using a questionnaire.

Each stress data was binarized using the threshold values described in the papers. When the threshold value does not exist, binarization classification was performed based on the average value of the acquired data.

1-2 Development of evaluation models

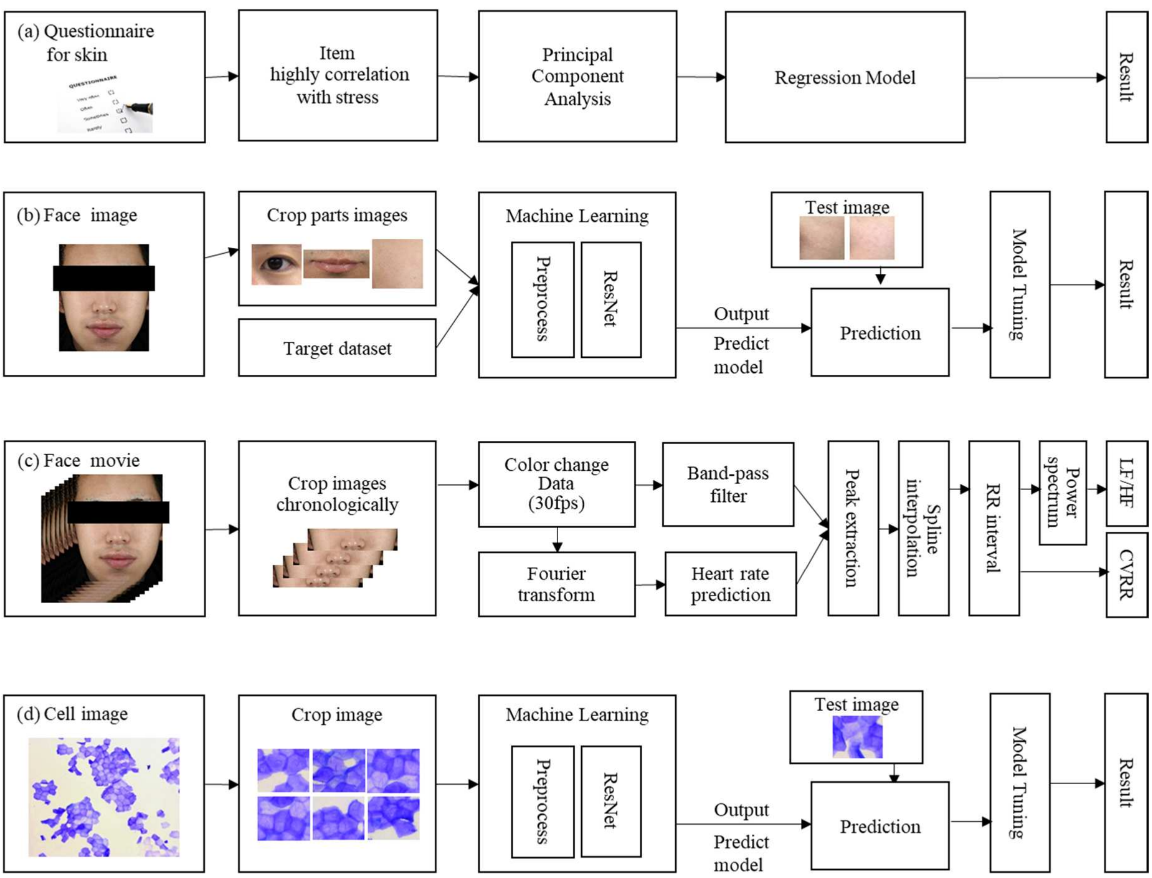
Models were created to predict stress states using various types of face data. Kinds of machine learning and objective variables were selected according to the characteristics of the face data. In the present study, we try to establish technologies of "evaluate what the human does not detect", unlike the general machine learning task "the machine also detects what the human can detect". As a previous study similar to our challenge, the model evaluating the subjects' political principles using face data were developed at accuracy of about 0.7[22]. Hence, referring to this similar study, the criteria of accuracy (using validation data) for establishing models were set for >0.700 in this study.

1-2-1 Model for evaluating stress state using subjective questionnaire about skin

Evaluation models of stress states (Chalder fatigue scale, mental fatigue scale, physical fatigue scale, and Athens Insomnia Scale, isoprostane, 8-OHdG, vanillylmandelic acid, homovanillic acid, dROM, Oxidative Stress Index) were created using the responses to 25 items of skin-related questionnaires, gender and age data. First, we conducted a correlation analysis between the questionnaire items related to skin and the stress state, and found 15 questionnaire items with a correlation coefficient of 0.3 or more.

The items are: Do your skin or lips dry out easily? Do your cheeks become inflamed and hot? Does your skin have urticaria easily? When you scratch your skin, do you tend to get marks on it? Do you have reddish-purple dots or patches on your skin? Do you sweat without doing anything? Do you bruise easily? Does your upper eyelid swell easily? Do you have dark circles under your eyes? Do you develop age spots easily? Do you have pale lips? Is your forehead greasy? Are your lips redder than other peoples? Is your nose greasy and shiny? Do you get pimples easily? Next, we created a regression model using the items, age and gender information. In addition, a principal component analysis is performed as a pre-processing step in the model creation process to verify the usefulness of dimensionality reduction (Fig. 1 (a)). In this study, we created 540 evaluation models for each objective variable by combining the types of regression analysis (linear regression, logistic regression, ridge regression, lasso regression, random forest, SVM) and patterns of dimension compression, and searched for the evaluation model with best accuracy. Five cross-validations (learning 8: verification 2) were performed to evaluate the model, and the accuracy and F1 score (harmonic average of precision and recall) were calculated. We constructed three types of models: combined gender models and gender-separated models.

Fig .1 Flow of stress states evaluation processes and result outputs using four kinds of skin data



1-2-2 Evaluation of stress state from facial images

Evaluation models of stress states (Chalder fatigue scale, Pittsburgh Sleep Quality Index, Frustration score, isoprostane, 8-OHdG, vanillylmandelic acid, homovanillic acid, dROM, Oxidative Stress Index) were created using facial images (Fig.1(b)). Modeling was performed separately using four types of facial images (whole face, cheeks, eyes, mouth). As a deep learning technique, ResNet [23], which is widely used for image-based classification problems, was selected after preliminary studies. Five-fold cross-validations (learning 8: verification 2) were performed to evaluate the model, and the accuracy and F1 score (harmonic average of precision and recall) were calculated. To develop better evaluation model, hyperparameter tuning was performed. Hyperparameter tuning, which is a method generally used to improve the accuracy of machine learning, is optimization of settings of machine learning algorithms. Since facial images may differ greatly between males and females, we did not create combined gender models, but gender-separated models.

1-2-3 Evaluation of stress state using face movie

Evaluation models of stress states (CVRR, LF/HF) were created using facial movies (Fig. 1(c)). Referring to the paper [24, 25], original methods with high accuracy were developed. Each image in the movie was separated into frames (30fps), then the central part of face was detected using face detection technology (face landmark detection [26]), and the changes of the color component (x =Green / (Red + Green + Blue)) were calculated. Then the data were Fourier transformed (Welch`s method) and the mode frequency of the color component was detected as the heart rate. After the noise of the data were eliminated using a band-pass filter, Spline interpolation was performed to convert the data into equal time interval data (RR interval). CVRR was calculated using the mean (μ) and standard deviation (σ) of the RR interval with the following formula: $CVRR=\sigma/\mu\times100$ (%). Then “RR interval” was Fourier transformed (Welch`s method) to analyze power spectrum to calculate low frequency (0.04–0.15Hz) and high frequency (0.15–0.4 Hz) bands in heart rate variability. LF/HF is the ratio of low frequency to high frequency.

1-2-4 Stress state evaluation model using stratum corneum images

Evaluation models of stress states (Chalder fatigue scale, mental fatigue scale, physical fatigue scale, Athens Insomnia Scale, isoprostane, 8-OHdG, vanillylmandelic acid, homovanillic acid, dROM, Oxidative Stress Index) were created using stratum corneum images (fig.1 (d)). The stratum corneum cell images were obtained in a grid shape of 128px×128px. The images were rotated and inverted every 90 degrees. This made it possible to obtain invariance using rotated and inverted images and perform analysis regardless of the orientation of the photographed cells. Images with less than 70% cell area were excluded. As a deep learning technique, ResNet was selected after preliminary studies. Five-fold cross-validations (learning 8: verification 2) were performed to evaluate the model, and the accuracy and F1 score were calculated. To develop better evaluation model, hyperparameter tuning was performed.

1-2-5 Visualization of areas used for evaluation models

Using the established evaluation model, the areas used for evaluation were visualized. In deep learning, the artificial intelligence program itself discovers important features of images in each predictive model in the process of creating a model. By visualizing the features, it is possible to understand which parts of the model are being discriminated, and this helps to confirm the validity of the model creation. GradCam [27] was used for feature visualization. With this method, the features of an image are shown by a heat map, and the redder the color, the stronger the characteristics of the prediction model.

2. Pilot study using a smartphone application prototype

By creating a smartphone application prototype that integrated stress state evaluation technologies of 1-2-1 and 1-2-3 with the self-care relaxation program (Fig.2), the usefulness of combining technologies for visualizing one's stress state with self-care action was confirmed. The relaxation program consists of two connected components: (1) A vibration that starts at the same frequency as the subject's heartbeat and goes down to 50 bpm (beats per minute). (2) Relaxing music made according to changes in the rhythm of the vibration (the type of music varies depend on the result of stress states of each individual). This program is based on our previous preliminary studies of vibration solutions (data not shown).

In this study, the validation of the usefulness of vibration with music program was carried out, then validation tests of the prototype for one week and one month-use were carried out. The total number of participants for validation tests was 1584.

Fig. 2: Brief description of the application prototype

The prototype consists of combination of analytical technology with digital relaxation contents that is provided immediately after analysis. A seamless experience from analysis to solution is three steps.

1. Facial Analysis 2. Results 3. Self-Care action

Facial information is collected using the questionnaire, and data on the changes of facial color is calculated from the facial movie. (Application of technology1-2-1 and 1-2-3)

Stress states of Chalder Fatigue scale, mental fatigue, physical fatigue, CVR-R, LF/HF, and heart rate are calculated.

Personalized digital contents based on the result of the analysis are provided. (Application of technology 2-1-1)

<u>2-1-1 Effects of single use of vibration and music program</u>

If the experience of the vibration and music program reduces stress sufficiently, the longtime use of the program is assumed to be able to improve body, mind, and facial conditions. Hence, we first confirmed the effectiveness of a single use of the program. To demonstrate the effectiveness, 36 healthy male subjects were tested by comparing the program use group with the non-use group (random crossover study). The subjects were exposed to 14-minutes stress of ATMT [28] and 2-back tasks [29]. In the former task, many of numerical notations appear on the computer screen and the subject searches for the designated number. In the latter task, the alphabet is displayed in order and the subject recalls the alphabet displayed two letters before the time to answer. After stress exposure, control group freely rested (14 minutes) on chair and the other groups experienced the self-care relaxation program (4 minutes) before freely resting (10 minutes). For confirming effect of vibration, two user groups were set. One experienced vibration with music program (group 1), and another experienced the music program only (group 2). Stress states of cortisol concentration in saliva, VAS items (stress, tension, irritability), and emotional questions (restless, animated, active, relaxed, energetic) using 4 score (Not at all, Only a little, Somewhat, Definitely) were collected at two points (just after stress exposure and after resting). The change of stress states between the two groups with control was compared by Wilcoxon signed rank test followed by Bonferroni correction.

2-2-2 Effects of one-week use of the prototype on self-care awareness

If people know their stress status seeing their own faces on a daily basis, they will realize the importance and necessity of self-care. 862 healthy males and 625 healthy female subjects were tested to confirm the effectiveness on self-care awareness. Subjects were asked to use the prototype for one week freely, then changes of their self-care awareness were collected by questionnaire. The question is "Have you noticed anything about self-care awareness after using the application?". From the answers below, subject selected what they felt after using the prototype. The answers were "I found that I hadn't noticed about my condition." "I felt that I need to know myself more." "I found self-care is important." "I decided to treat myself more." "I felt it was important to take a good look at myself at least once a day. " "I realized the importance of taking relaxation occasionally for me." or "no comment". The subjects were divided into three groups by the numbers of prototype use. The average of total number of positive answers among three groups were compared by Steel-Dwass test.

2-2-3 Effects of one-month use of the prototype on the body

In total eighty-five healthy female subjects were tested to confirm the effectiveness of on body after one month use. The stress states of Chalder fatigue scale and salivary IgA (biomarker of long-term stress accumulation [30]) were used in this study. Data were collected before and four weeks after using prototype (Chalder fatigue scale data were also collected at two weeks after using prototype). The Wilcoxon signed-rank test was used to test for change in the Chalder fatigue scale and change in IgA concentration. And Spearman's correlation test was used for the correlation analysis between the improvement in the Chalder fatigue scale and the number of times the app was used.

2-2-4 Effects of one-month use of the prototype on state of mind

Fifty-five healthy female subjects were tested to confirm the effectiveness on state of mind after one month use. The PANAS (Positive and Negative Affect Schedule) scale [31] and responses to the question of self-acceptance were collected using questionnaire. The PANAS scale consists of positive affect scale (PANAS positive) and negative affect scale (PANAS negative). The two scales are largely uncorrelated. The Wilcoxon signed-rank test was used to test for the changes in PANAS negative and positive between pre-use and post-use of prototype. In the self-acceptance question, subjects were asked to respond to the question "Are you accepting yourself as you are?", and to select one answer from* "1. Not at all. " "2. Only a little." "3. Sometimes." "4. Half the time." "5. Usually." "6. Most of the time." "7. Definitely." For the analysis, the ratio of total number of negative response (from 1 to 3), was calculated, and changes in this ratio were tested between pre-use and post-use of 4weeks with the chi-square test.

2-2-5 Effects of one-month use of the application on the skin

Forty-five healthy male subjects were tested to confirm the effectiveness on the skin after one month use. Since we would like to conduct the study under controlled conditions by eliminating the effects of sex hormone fluctuations on the skin, male individuals were selected for this study. Subjects were randomly divided into two groups, one using the application and the other not, and analyzed changes in skin condition and cortisol (a stress-related factor also known to be related to skin [32-35]). Skin conditions were analyzed using VISIA® Evolution (Canfield Scientific Inc.), and the scores of Brown Spot Count, Pore Count, Porphyrin Count, Red Spot Count, Red Vascular Count, Spot Count, Texture Count, UV Spot Count, Wrinkle Count were used for the analysis. The concentration of cortisol in saliva was used in the study. The Wilcoxon signed-rank test was used to test the significance of the one month change in both the app-using group and the non-using group.

Results.

1. Stress state analysis technology using facial information

Table-1 (a) shows the details and accuracy of the stress state evaluation model based on face questionnaire information. Both the combined gender models and the separated gender models had an accuracy of >0.700 for models assessed with the Chalder fatigue scale, mental fatigue scale, and physical fatigue scale. The accuracy of the evaluation model for the Athens Insomnia scale in male model was >0.700. On the other hand, a reliable model could not be constructed for blood and urine stress markers.

Table-1(b) shows the details and accuracy of the stress state evaluation model using face images. The evaluation models had an accuracy >0.700 were those using the Chalder fatigue scale, mental fatigue scale, Pittsburgh Sleep Quality Index, Frustration score, isoprostane, vanillylmandelic acid, dROM, Oxidative Stress Index. The accuracy of the evaluation models for 8-OHdG and homovanillic acid were 0.682 and 0.697 respectively. It was also found that the appropriate areas of the face used for evaluation varied greatly depending on the target to be evaluated. Fig. 3 shows the results of the facial location images acquired using GradCam. These images were used for machine learning. It can be confirmed that the model is constructed using the facial location shown in Table-1(b).

Table-1 (c) shows the evaluation accuracy of the model for assessing the autonomic nervous state using facial moving images. It was confirmed that models with a correlation coefficient >0.700 were created for heart rate, CVRR, and LH/HF.

Table-1(d) shows the details and accuracy of the stress state evaluation model using stratum corneum images. The combined gender models with evaluation accuracies exceeding 0.700 were those that assessed the Chalder Fatigue Scale, isoprostane, homovanillic acid, and Oxidative Stress Index. Compared to the combined gender model, gender-separated models with 5% higher accuracy were found. The models with higher accuracy of evaluation using male data were those for vanillylmandelic acid, homovanillic acid, and using female data was that for Oxidative Stress Index. Using GradCam, it was confirmed that the evaluation models are constructed using the cellular sites in the images (Data not shown).

Table 1: Details and accuracy of the stress state evaluation model using facial information

Four types of face data were used to create evaluation models of stress state. They include questionnaire information (a), face images (b), face movie image (c), and stratum corneum images (d). In creating the models, multiple models were testified and the model with the best accuracy was selected. Models with accuracy > 0.700 are shown in red.

(a) Source: Questionnaire information

	Methods	Details	Sex	n	Model	PCA	Accuracy	F1score
Stress scale test	Questionnaire	Chalder Fatigue Scale	male&female	1411	SVM	-	**0.744**	**0.676**
			female	654	Linear	1	**0.781**	**0.679**
			male	757	Logistic	1	**0.782**	**0.703**
		Mental fatigue scale	male&female	1871	Linear	-	**0.783**	**0.749**
			female	875	Logistic	1	**0.742**	**0.700**
			male	996	Lasso	1	**0.804**	**0.730**
		Physical fatigue scale	male&female	1871	Linear	-	**0.777**	**0.742**
			female	875	Linear	2	**0.789**	**0.725**
			male	996	Lasso	1	**0.818**	**0.742**
		Athens Insomnia Scale	male&female	1411	Linear	-	0.668	0.648
			female	654	RandomForest	-	0.679	0.668
			male	757	Lasso	1	**0.701**	**0.669**
Physiological test	Urine test	Isoprostane	Reliable model could not be constructed					
		8-OHdG						
		Vanillylmandelic acid						
		Homovanillic acid						
	Blood test	dROM						
		Oxidative Stress Index						

(b) Source: Face image

	Methods	details	Area	Sex	n	Accuracy	F1score
Stress scale test	Questionnaire	Chalder Fatigue Scale	mouth	female	196	**0.753**	**0.644**
				male	199	0.695	0.621
		Pittsburgh Sleep Quality Index	whole face	female	196	**0.703**	**0.690**
				male	199	**0.703**	**0.675**
		Frustration score	mouth	female	196	**0.737**	**0.684**
				male	199	**0.703**	**0.682**
Physiological test	Urine test	Isoprostane	mouth	female	196	0.684	0.674
				male	199	**0.726**	**0.698**
		8-OHdG	eye	female	196	**0.711**	**0.696**
				male	199	0.653	0.641
		vanillylmandelic acid	eye	female	196	**0.726**	**0.725**
				male	199	0.637	0.627
		Homovanillic acid	mouth	female	196	**0.705**	**0.665**
				male	199	0.689	0.669
	Blood test	dROM	mouth	female	196	**0.826**	**0.659**
				male	199	**0.732**	**0.703**
		Oxidative Stress Index	cheek	female	196	**0.879**	**0.686**
				male	199	**0.716**	**0.709**

Table 1 (continuing)

(c) Source: Face movie images

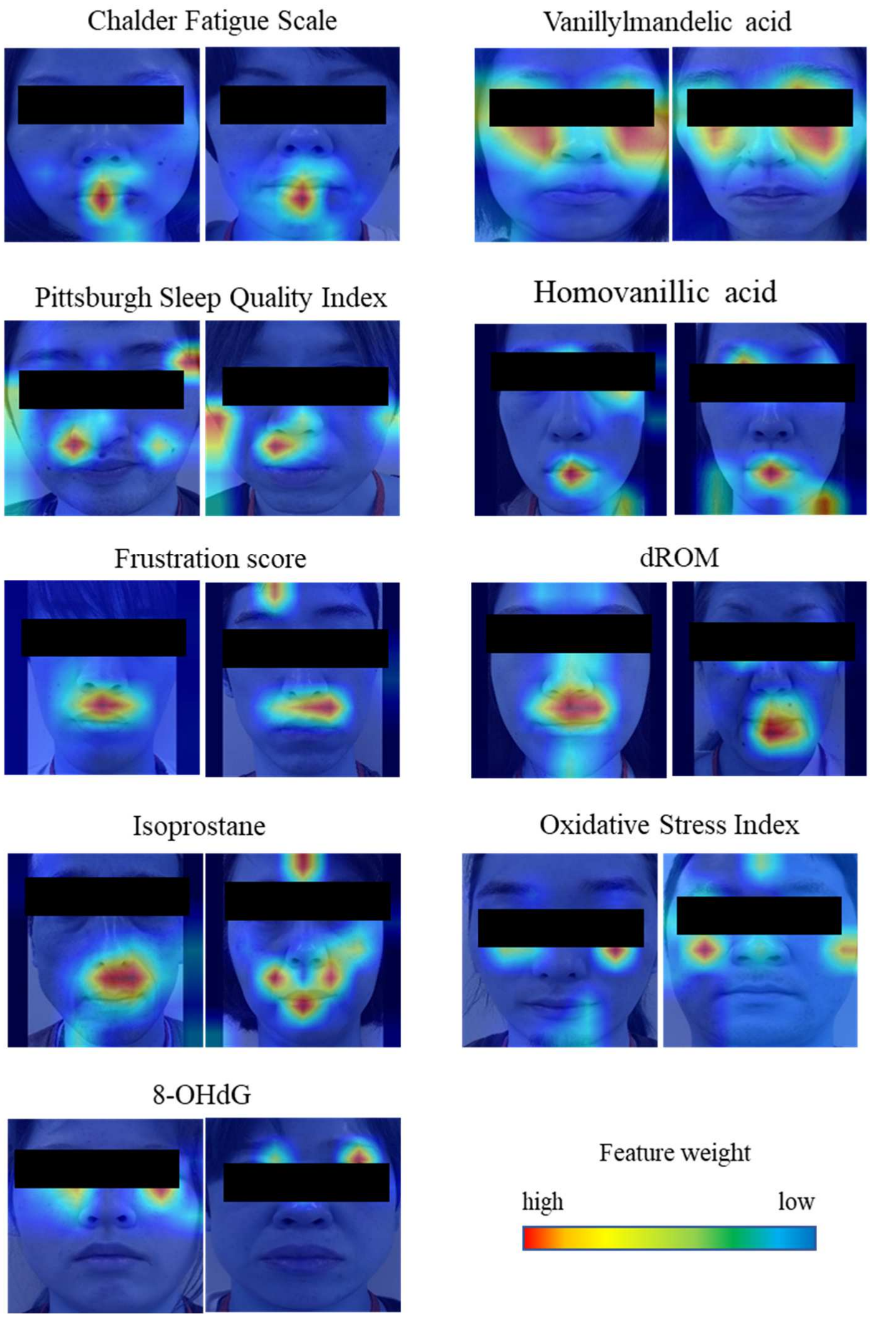
	Details	n	Correlation coefficient or Accuracy
Physiological test	Heart Rate	56	**r=0.988**
	CVRR	56	**r=0.755**
	LF/HF	56	**r=0.722**
	LF/HF Rank	56	**Accuracy=0.875**

(d) Source: Stratum corneum images

	Methods	Details	Sex	n	Accuracy	F1score
Stress scale test	Questionnaire	Chalder Fatigue Scale	male&female	1411	**0.759**	**0.625**
			female	654	0.663	0.537
			male	757	**0.733**	**0.558**
		Mental fatigue scale	male&female	1871	0.695	0.643
			female	875	0.610	0.529
			male	996	0.624	0.561
		Physical fatigue scale	male&female	1871	0.602	0.543
			female	875	0.656	0.537
			male	996	0.642	0.571
		Athens Insomnia Scale	male&female	1871	0.626	0.659
			female	875	0.561	0.520
			male	996	0.621	0.658
Physiological test	Urine test	Isoprostane	male&female	851	**0.714**	**0.539**
			female	365	0.690	0.594
			male	486	**0.783**	**0.618**
		8-OHdG	male&female	851	0.679	0.644
			female	365	0.571	0.641
			male	486	0.664	0.563
		Vanillylmandelic acid	male&female	327	0.664	0.647
			female	110	0.654	0.586
			male	217	**0.728**	**0.618**
		Homovanillic acid	male&female	327	**0.704**	**0.554**
			female	110	0.670	0.667
			male	217	**0.774**	**0.519**
	Blood test	dROM	male&female	327	0.687	0.575
			female	110	**0.935**	**0.594**
			male	217	0.574	0.552
		Oxidative Stress Index	male&female	327	**0.743**	**0.670**
			female	110	**0.841**	**0.615**
			male	217	0.589	0.569

Fig. 3: Visualization of image features using GradCam

The results of visualizing the features using the GradCam in the images where the model evaluation was correct. The features of an image are shown by a heat map, and the redder the color, the stronger the characteristics of the prediction model.

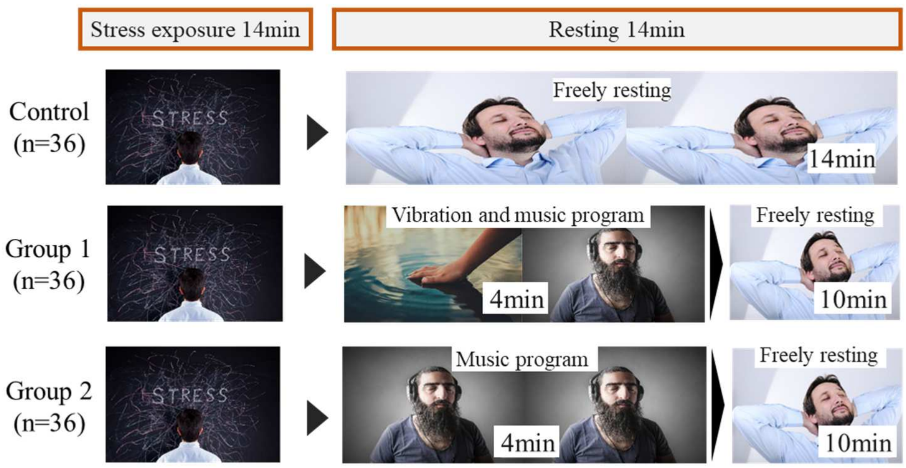


2. Pilot study using a smartphone application prototype

Fig. 4 shows the results of the validation of the usefulness of vibration with music program. After exposure to stress, we divided the participants into three groups: control group freely rested after stress exposure, and the other groups that experienced the relaxation program of vibration with music (Group 1), or program of music (Group 2) before freely resting. Comparison of the stress state using program groups against the non-using group were conducted. The results in Group 1 show all of the significant improvements in salivary cortisol levels, stress, and relaxed score compared to the group that did not use the program. On the other hand, the results in the Group 2 show only the significant improvements in stress, and relaxed score. These results confirm the effectiveness of vibration with music program.

Fig. 4: Effects of vibration with music program on resting

Subjects randomly experienced three kinds of resting in a three-day period. The effects of the vibration with music program and music program, were tested compared to freely resting without program. (36 males aged 25-50 years Randomized cross-over study)



Group	Data	Changes between pre- and post-resting (mean ± SE)	P-value for difference with control
Control	Stress (Vas score)	-15.6 ± 2.2	-
	Relaxed score	0.28 ± 1.3	-
	Cortisol (mg/dL)	-0.043± 0.01	-
Group 1 (vibration with music)	Stress (Vas score)	-21.4± 2.7	**0.004***
	Relaxed score	0.86 ± 1.3	**0.008***
	Cortisol (mg/dL)	-0.083± 0.01	**0.006***
Group 2 (music)	Stress (Vas score)	-21.0± 2.8	**0.027***
	Relaxed score	0.72 ± 1.6	**0.016***
	Cortisol (mg/dL)	-0.070 ± 0.02	0.153

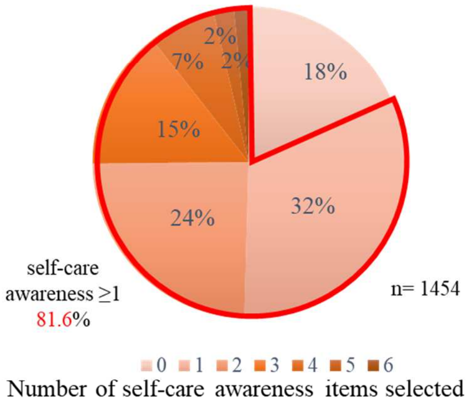
*p<0.05 (Wilcoxon signed rank test followed by Bonferroni correction)

Fig. 5 summarizes the results of changes in self-care awareness after using the smartphone application prototype for one week. They were aggregated by asking participants to submit the checklist regarding self-care awareness. By using the prototype, 81.6% of participants responded with a positive change of one or more, and the total number of positive changes was increased as the number of times of usage was increased.

Fig. 5: Effects of one-week use of the prototype on self-care awareness

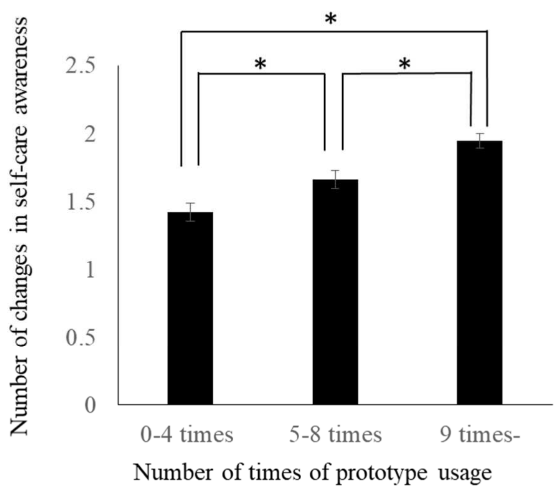
The effects of prototype usage on self-care awareness were analyzed by composition ratio of the number of positive changes in self-care awareness (a) and by comparison study divided with the frequency of prototype usage (b).

(a) The composition ratio of positive changes in self care awareness



Check list of self-care awareness
1. I found that I hadn't noticed about my condition.
2. I felt that I need to know myself more.
3. I found self-care is important.
4. I decided to treat myself more.
5. I felt it was important to take a good look at myself at least once a day.
6. I realized the importance of taking relaxation occasionally for me.

(b) The relationship between the number of prototype usage and changes in self-care awareness



n= 1454, mean ± SE, *p<0.05 (Steel-Dwas test)

Fig. 6 summarizes the results of investigating the effects on the body after using the prototype for one month. Significant improvement was confirmed in the Chalder fatigue scale (Fig. 6 (a)), and the amount of change in this improvement tended to correlate with the number of times of prototype usage (p = 0.059) (Fig. 6 (b)). In addition, the IgA level in saliva, which is a long-term stress marker, was confirmed to significantly increase after using the prototype (Fig. 6 (c)). These results confirmed the positive impact of the body by using the application.

Fig. 6: Effects of one-month use of the prototype on the body

The effects of prototype usage on the body were analyzed, focusing on Chalder Fatigue scale (a,b) and salivary IgA (c) .

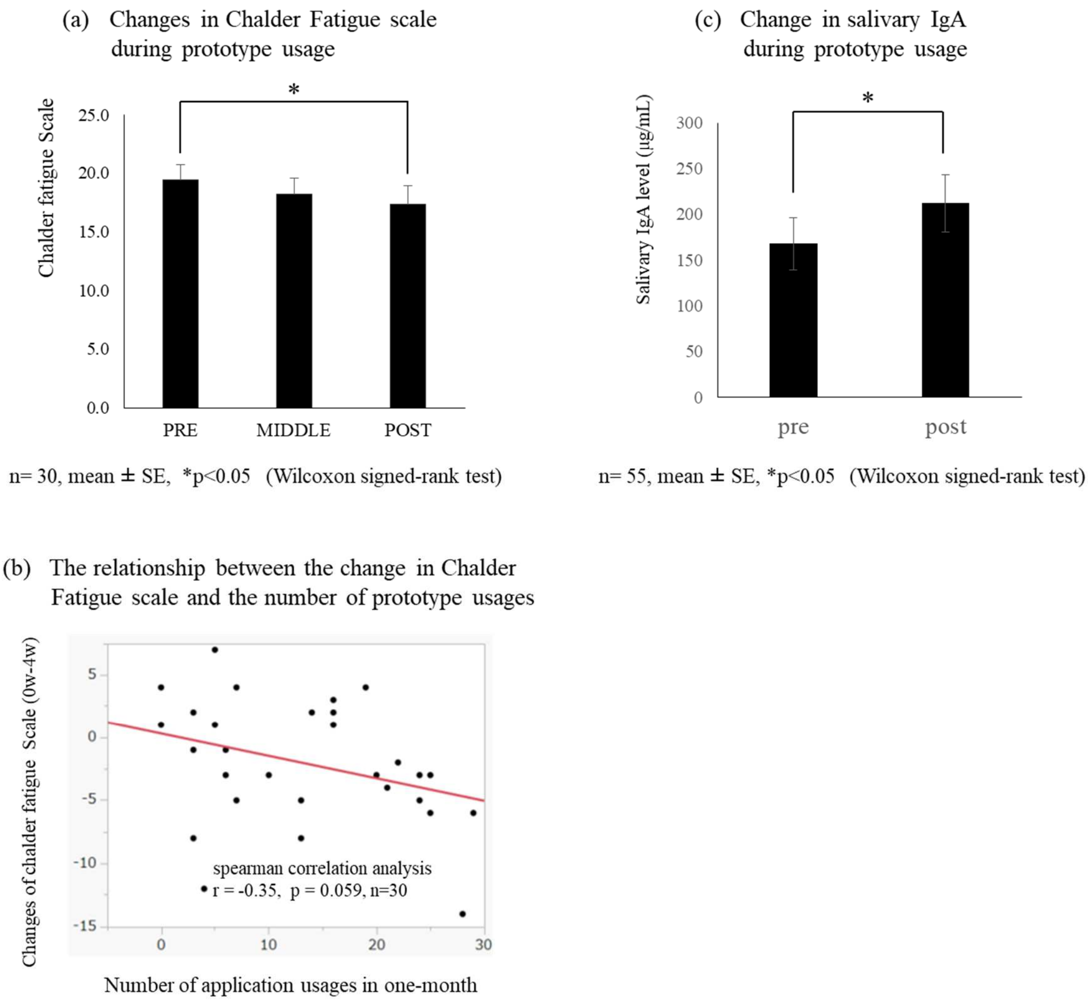


Fig. 7 summarizes the effects on the mind after using the prototype for one month. A significant decrease in the PANAS negative score was confirmed (Fig. 7 (a)). For the PANAS positive score, in the group with below average score (24.6) at pre-use, a significant increase in the PANAS positive score was confirmed (Fig.7 (b)). In addition, the ratio of negative answers (scores 1 to 3) to the question "Are you accepting yourself as you are?" was significantly reduced (Fig.7 (c)). These results confirmed the positive impact on a negative mindset.

Fig. 7: Effects of one-month use of the prototype on state of mind

The effects of prototype usage on state of mind were analyzed, focusing on PANAS negative (a) and PANAS positive (b), and level of self-acceptance (c).

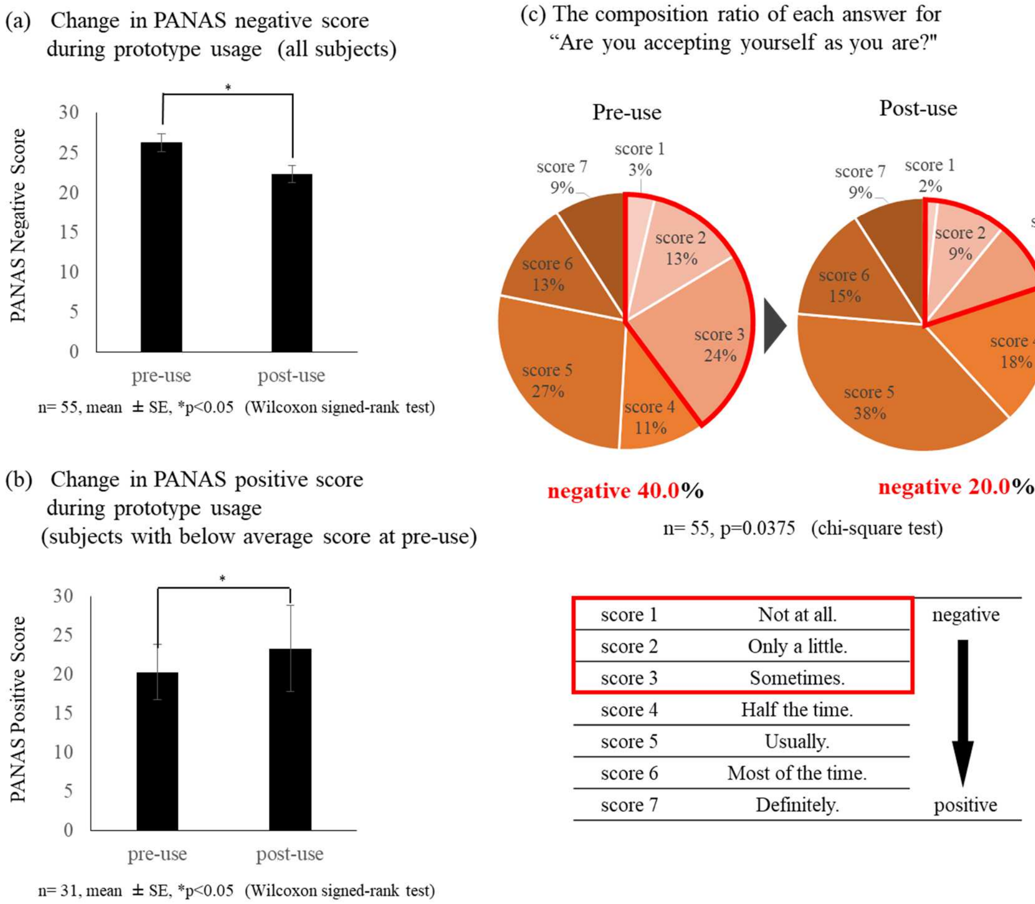


Fig.8 summarizes the effects on the skin after using the prototype for one month. Analysis of skin condition using VISIA showed no significantly change in the prototype non-using group. On the other hand, in the prototype using group, the wrinkle count, pore count, and UV spot count were significantly decreased. In addition, salivary cortisol levels were significantly improved in only the prototype group (Fig. 8(a)). Fig. 8(b) shows examples of skin improvement after using the prototype. These results confirmed the positive impact of the skin by using the application.

Fig. 8: Effects of one-month use of the prototype on skin

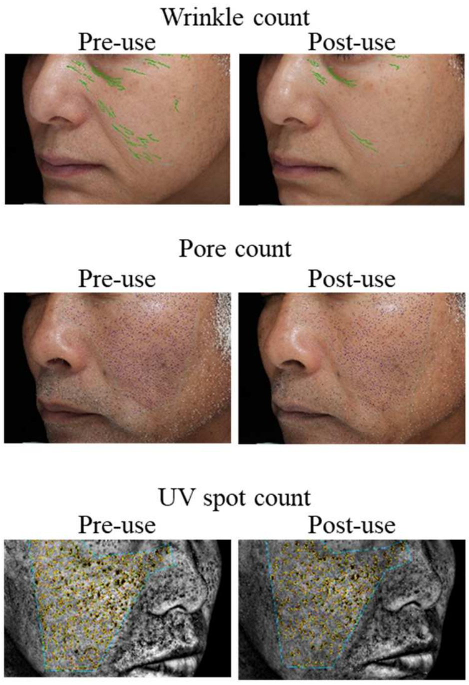
The effects of prototype usage on skin were analyzed focusing on Visia score and salivary cortisol, values at pre-use and post-use are shown in (a). Pictures of example of skin improvement are shown in (b) .

(a) Change in Visia score and salivary cortisol

		Group	Pre-use	Post-use	Change	p-value
Visia DATA	Wrinkle Count	Non-using	12.74	12.30	-0.435	0.465
		Using	14.86	12.82	-2.045	**0.032***
	Pore Count	Non-using	882.78	858.39	-24.392	0.244
		Using	1055.32	1010.86	-44.460	**0.006***
	UV Spot Count	Non-using	184.00	180.22	-3.783	0.074
		Using	195.46	187.55	-7.910	**0.012***
	Brown Spot Count	Non-using	224.61	223.00	-1.609	0.341
		Using	239.50	238.36	-1.136	0.411
	Porphyrin Count	Non-using	608.17	556.09	-52.087	0.459
		Using	849.64	905.23	55.591	0.195
	Red Spot Count	Non-using	69.78	71.13	1.348	0.468
		Using	65.64	64.23	-1.409	0.570
	Red Vascular Count	Non-using	76.35	72.57	-3.783	0.115
		Using	72.41	73.64	1.227	0.571
	Spot Count	Non-using	100.96	101.91	0.956	0.356
		Using	104.82	104.14	-0.682	0.366
	Texture Count	Non-using	1527.87	1442.22	-85.650	0.092
		Using	1699.45	1651.09	-48.360	0.219
Saliva	Cortisol (mg/dL)	control	0.28	0.31	0.035	0.424
		Using	0.34	0.26	-0.072	**0.003***

n= 45 (app-using group =22, non-using group = 23), *p<0.05 (Wilcoxon signed-rank test)

(b) Examples of skin improvement



Discussion.

The objective of this study is to construct a "skin-centered self-care system" that uses skin analysis as a starting point to learn about one's own stress condition, and provides solutions through sensory stimulation via the skin. We found very positive results in both skin-based stress analysis technology and skin-based self-care solutions.

The first half of this article described the construction of an analysis technique using facial data. In that section, we aimed to build a simple and comprehensive stress monitoring technology. This is because, although stress monitoring is important for all people in today's society, it is difficult to accurately grasp the state of stress due to the variety of stress symptoms and the characteristics of dynamic fluctuations. On the other hand, since the face and skin are places affected by the accumulation of stress, we thought it would be possible to construct a technology to evaluate the state of stress using facial information. In this study, we used machine learning technology to construct a stress state evaluation model with an evaluation accuracy of more than 70% using four types of facial information. As a result, evaluation models evaluating 15 types of stress states were developed (Table-1). They include models that predict stress markers in blood and urine. The fact that these multiple stress states can be easily and comprehensively analyzed using the facial skin without collecting biological components is considered to be especially useful in health management in the workplace, where stress is high on a daily basis. In fact, JAXA (Japan Aerospace Exploration Agency) is also interested in potential of this technology, and our technology was adopted as joint development research to develop a tool for astronaut health management [36]. In the near future, "this new skin analysis technology" will be utilized in spacecrafts.

Apart from its usefulness for employee health care in the workplace, from the perspective of personal use, understanding the stress state in daily life has the advantage of improving self-care motivation and changing awareness of self-care. This is very important for behavior change toward self-care action. In our study, as shown in Fig. 5, the awareness of self-care improved as the experience of knowing one's stress state. This skin-based stress analysis is thus considered very promising for health management in the workplace and for individuals. Currently the technology was created using Japanese data, and in the future it will be adapted to include other ethnicities. Nevertheless, this study is very important for our industry, because it shows the possibility that we can expand the significance of cosmetic technological value to other fields.

The second half of the paper examined the possibility of a self-care solution. Even if one's stress condition is identified from facial analysis, it is still difficult for many people to take and continue self-care actions if the methods don't meet two conditions: easy for anyone to do and gives feeling of effectiveness. Hence, we built original solutions by applying the knowledge from previous studies (manuscript under review) that people tend to feel relaxed when they experience vibrations whose rate are the same as their heart rate. Then we created a smartphone application prototype that combines stress monitoring technology with the digital solution, and demonstrated the importance of daily self-care practices. We found the positive changes in the body regarding fatigue and salivary stress markers (Fig. 6), and positive changes in the mind regarding negative emotions and self-acceptance (Fig. 7) after one month of use. In addition, we found a decrease in the stress hormone cortisol, and improvements in skin condition (fig.8). Since it is known that stress causes skin troubles and some of them are thought to be involve cortisol [32-35], these results are promising. Although this is a pilot study and there are many things to consider, such as demonstration tests on women, mechanism research, and synergistic effects with cosmetics, it also has a great impact for the cosmetic industry, in that the skin condition was improved by stress management (internal care), not cosmetics (outer care). This is because we can find the possibility of "non-cosmetic skin care," which improves the skin condition by a new approach, stress management.

In summary, we constructed a "skin-centered self-care system" that uses skin analysis as a starting point to learn about one's own stress condition, and, based on the results of the analysis, provides individualized relaxation programs focused on sensory stimulation.

Conclusion.

This study identified the intersection of beauty and "wellbeing/wellness" through the application of skin analysis technology. This means skin care, mental care, and body care can be achieved simultaneously, with the skin analysis technology as the starting point.

Acknowledgments.

The research was supported by a grant for FemTech support service demonstration project of the Ministry of Economy, Trade and Industry of Japan. We would like to take this opportunity to express our deepest gratitude.

Conflict of Interest Statement.

This study was funded by POLA Chemical Industries besides a grant mentioned above.

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