Design and use of a gender-neutral, individualized wrinkle prediction model

Ken Suematsu[1], Kana Ochiai[2], Miki Nakanishi[3], Rie Nakamura[1]
[1] Advanced Technology Research Laboratories, KOSÉ Corporation, Tokyo, Japan
[2] IT Management Dept., KOSÉ Corporation, Tokyo, Japan
[3] Dermatology and Cosmeceutical Research Laboratories, KOSÉ Corporation, Tokyo, Japan

Abstract

Wrinkles progress steadily with age, and their gradual changes are difficult to notice. Therefore, selecting and continuing a cosmetic strategy for the predictive prevention of wrinkles is not easy for consumers. In a previous study, we developed an individualized wrinkle prediction model to predict future wrinkle profiles among middle-aged women and identify individual wrinkle acceleration factors that should be considered as part of a wrinkle prevention plan. In this study, we extended the scope of the model and conducted a comprehensive evaluation of its usefulness as a practical aid to wrinkle prevention. First, we obtained new data on male subjects to expand the target population and updated the wrinkle prediction model. Next, we packaged the model into a practical, web-based, customer-focused tool that can be accessed from a mobile device. Then, we conducted a randomized controlled trial on 115 men and women to verify the tool's effectiveness. As input to the web-based system, the tool uses wrinkle predictors obtained from a captured image taken on the device together with information directly entered by the user. Our results confirmed good prediction performance of the updated model used in the tool. Results also showed that use of the tool significantly increased confidence in continuing wrinkle prevention behaviors among users, regardless of gender. These findings suggest that the gender-neutral wrinkle prediction model developed in this study may be a useful tool to support the habituation of predictive prevention of wrinkles.

Key words: wrinkle, prevention, statistics, digital, modeling

1. Introduction

The steady progression of wrinkles with aging causes chronic and ongoing psychological distress for people who desire a youthful appearance [1-3]. The face is a focus point for wrinkles, and wrinkles that have become particularly severe are difficult to correct, creating psychological, and physical burdens. In recent years, research aimed at decreasing the risk of future aging, including wrinkles and spots [4-7], has been conducted extensively, and the importance of proactive and predictive prevention of aging phenomena is becoming more widespread. However, the progression of wrinkles and the associated risk factors of aging vary greatly from individual to individual. In addition, the progress of wrinkles is slow and difficult to notice, making it a challenge for people to select and maintain the most appropriate predictive preventive cosmetic strategies and services for their own wrinkle progression.

In a previous study, we developed a wrinkle prediction model that can accurately predict an individual's future wrinkles and suggest associated wrinkle acceleration factors that can be addressed as an approach for predictive prevention [8]. To create the model, physical properties representing skin surface conditions and the degree of wrinkle progression were repeatedly measured over a 7-year period on the same middle-aged Japanese women. Based on the obtained observation data over time, the model was developed and reported in accordance with the TRIPOD statement [9], a guideline for the development of multivariate prediction models in the field of medicine. Preliminary results suggested that this model could serve as a useful guide to optimize wrinkle prevention care and cosmetic strategies for individuals. However, the model did not consider gender differences, which limited its target audience. Also, the effectiveness of the model in providing optimized wrinkle prevention information for individual consumers was not verified.

In the clinical field, the effectiveness of digital technology and digital tools in preventing the onset and severity of disease has been attracting attention. It has been suggested that by capturing information on individual patients' diseases and conditions and accurately predicting their prognosis, treatment and lifestyle guidance policies can be optimized for each patient, thereby improving disease prognosis [10,11]. In addition, the support provided by evidence-based digital mobile tools has been shown to improve the ability and motivation of patients, as well as nonpatients, to self-manage, change behaviors, and implement recommended care for predictive prevention [12]. That is, the provision of personalized information through digital technology is expected not only to reliably improve patient outcomes, but also to assist patients in their efforts to achieve and sustain behavior change and manage their disease.

Following this trend, herein, we present a consumer-focused, web-based tool that allows for personally optimized information on wrinkle prevention that can motivate consumers to follow an effective wrinkle prevention plan. First, we prepared a dataset of male wrinkle assessments and updated our original wrinkle prediction model to a gender-neutral model, expanding its scope and generalizability. Next, we embedded the model into a web application with the aim of making the wrinkle profile and predicted wrinkle acceleration risk factors easily accessible to individual customers. Finally, we conducted a randomized controlled trial of 115 men and women to verify whether the web-based tool was useful in motivating the consumers to follow an individualized wrinkle prevention action plan (Fig. 1).

2.Method

2.1 Wrinkle prediction model development in previous study

An observational study was conducted from 2011 to 2017 to assess the skin condition in healthy Japanese women. Data from a total of 48 women between the ages of 22 and 60 years who were observed at least once between 2011 and 2013 were used in the development of the wrinkle prediction model. The outcome was a wrinkle grade of 0 to 7 in increments of 0.25, graded by trained professional assessors in accordance with the guidelines established by the Society of Cosmetic Chemists [13]. Next, in addition to age, which has a relatively strong correlation with wrinkles, the following variables were selected as candidate variables for predicting wrinkles: skin moisture content, Transepidermal water loss, and sebum content, which are instrumental measurements of skin condition; L*, a*, and b* values, which are three indicators of skin color; the average value of each measurement during the study period. To develop the prediction model, a multivariate linear mixed-effects model was employed, introducing a variational effect in the intercept to account for the correlation of repeated measurements for each individual. For the selection of predictors, a stepwise method of variable subtraction was employed, and the combination of variables that minimized the AIC (Akaike Information Criterion) was adopted. Variable selection resulted in the following predictors being used in the final model: age, sebum content, the skin color a* value, and the skin color L* value averaged over the study period. A multiplication term between sebum content and the skin color a* value was used as an interaction term (Table 1). This combination of predictors resulted in a significantly higher accuracy than when all skin property values were used or when age alone was used. This suggests that the chosen skin conditions contribute significantly to the wrinkle profile of an individual. The final wrinkle prediction model was able to account for 87.9% (95% confidence interval (CI): 85.2-90.7) of the variance with a root

mean square error of 0.517 (95% CI: 0.382-0.661), confirming the model's high accuracy (Fig. 2).

2.2 Update to gender-neutral wrinkle prediction model

2.2.1 Participants

As new subject data for validation and updating the wrinkle prediction model, skin surface conditions including wrinkle status were collected for 80 Japanese men aged 25 to 63 years working for KOSÉ Corporation (Tokyo, Japan) in 2021. The evaluation of skin surface conditions including the conditions of wrinkles was conducted as in the previous study.

2.2.2 External validation and updating of wrinkle prediction model

In order to validate the wrinkle prediction model reported in the previous study, we updated the wrinkle prediction model using the newly acquired. In general, prediction models can be applied to new subjects, but they often show poor performance. Therefore, several statistical updating methods for existing models have been proposed by Harrell[14], Steyvrerg[15], and others, and these are widely used in practice. In this study, three relatively simple and versatile recalibration methods were employed. Method 1 assumed no change between the development and validation populations and no updating occurred. Method 2 allowed for subject diversity not reflected in the parameters and adjusted only the intercept of the original model. Method 3 allowed the effects of the predictors of the existing model to differ in the new population and adjusted the intercept and slope. However, it assumed that the relative effects of the predictors were similar. The updating method with the best apparent performance was used to develop a new gender-neutral model.

2.2.3 Performance evaluation of the updated wrinkle prediction model

The performance of the updated prediction model for each method was evaluated using calibration plots in addition to R^2 values and RMSE. Also, to measure the prediction accuracy of the updated model, wrinkle grades in 2021 were predicted for 23 men with wrinkle and skin surface condition measurements dating back to 2017 using 2017 as a baseline.

2.3 Develop tools based on gender-neutral wrinkle prediction model

Based on the updated wrinkle prediction model, we developed a practical customer-focused tool that can predict future wrinkles of individual consumers and provide easy-

to-follow information on wrinkle prevention optimized for the individual. In developing the tool, we examined approximate values for sebum, skin lightness, and redness, which are measurements made with specialized equipment, to obtain predictors that are necessary for wrinkle prediction. Since it has been confirmed in a previous study that people who self-identify as having oily skin have significantly more sebum than those who do not [16], the consumer's self-reported amount of sebum (on a 4-level scale) was used data for the wrinkle prediction model. Skin color information (brightness and redness) was obtained through the analysis of an image taken by the user on their mobile device using the AI Smart Shade Finder application, a skin color analysis tool provided by Perfect Corp. (Taiwan) that has a proven track record in skin diagnosis AI.

2.4 Randomized controlled trial to test the effectiveness of the wrinkle prediction tool on wrinkle prevention behavior

Finally, a randomized controlled trial was conducted to test the effectiveness of the customer-focused tool. The purpose of the efficacy test was to determine whether the use of the customer-focused tool could motivate wrinkle-preventive behavior in those who had begun to worry about wrinkles, compared to those who had not used the tool.

2.4.1 Participants

Japanese men and women between the ages of 26 and 34 who had begun to notice wrinkles were recruited via the Internet. Study participants were assigned by a stratified replacement block method to achieve a 1:1 male-to-female ratio in the intervention and control groups, with 60 participants in the intervention group and 55 in the control group ultimately participating in the study.

2.4.2 Creation of a survey form

To assess the extent to which participants were voluntarily motivated to engage in wrinkle-prevention behaviors, a questionnaire was developed to determine the four psychological components of the motivational phase of behavior, as proposed in the Health Action Process Approach (HAPA) by Schwarzer et al [17,18]. The components were 1) the intention to perform the behavior, 2) confidence in performing the behavior, 3) perceived risk of not performing the behavior, and 4) expectations of the consequences of performing the behavior. In this study, a total of 18 question with response items on a 7-point Likert scale were prepared, consisting of 3 questions regarding intentions toward wrinkle prevention behaviors, 7 questions regarding confidence, 3 questions regarding perceived risk, and 5 questions regarding expectations of results [18,19].

2.4.3 Creation of a digital book on wrinkle prevention methods

A digital book was created to provide study participants with general information about wrinkles. The digital book included information on the importance of prevention, factors that accelerate wrinkle progression [20-25], and indicators for self-assessment of wrinkle progression based on previous studies. Additionally, the relationship between average age and wrinkles and inter-individual differences in the degree of wrinkle progression were described. Finally, a checklist for participants to check their own wrinkles and skin condition, as well as simple care recommendations for these conditions, were included.

2.4.4 Procedure for Randomized Controlled Trials

Study participants responded to a survey form before and after the trial. For the intervention group, the trial consisted of viewing the digital book followed by an experience with a digital tool, while the control group only viewed the digital book. Viewing of the digital book and interacting with the digital tool took participants only a few minutes, and all responses to the survey were collected via the Internet (Fig. 3).

2.4.5 Statistical analysis for validation of intervention effectiveness through the use of digital tools

To determine the effectiveness of the tool, an analysis of covariance in the amount of change before and after the intervention for each group was conducted based on the responses to questions on voluntary motivation for wrinkle-preventive behavior. The covariates used in the analysis were the subject's gender, age, and degree of wrinkle concern. As a secondary analysis, a paired t-test was conducted on the pre- and post-intervention changes for each question in each group to verify the effects of each intervention. A 95% confidence interval and a threshold of $p<0.05$ were used to determine significant difference.

3 Result

3.1 Update to gender-neutral wrinkle prediction model

3.1.1 Participant

Details of the newly acquired male data compared to the subjects for whom the wrinkle prediction model was developed are shown in Fig. 4. Skin lightness (L* value), a predictor in the model, was significantly lower in the newly acquired data, and similarly, skin redness (a* value) was significantly higher. In other words, the new data suggested

that the skin surface condition of biological males is darker and redder in skin color. On the other hand, the relationship between wrinkle ratings and age was highly correlated in both data sets (development population: 0.775 (95% CI, 0.726-0.816), validation population: 0.839 (95% CI, 0.759-0.8939)), and the strength of the relationship was not significantly different.

3.1.2 External validation results and updates of wrinkle prediction model and performance evaluation

Our original prediction model was visually shown to systematically underestimate wrinkles for new subjects in the calibration plot. The performance was extremely low, R^2=0.03 (0.00-0.23) and RMSE=1.41 (0.93-1.89), suggesting that updating the model would likely have better prediction performance. In other words, the results indicated that biological gender differences should be considered. The results of method 2 (the intercept adjustment method) showed that the performance was improved to R^2=0.55 (0.46-0.64) and RMSE=0.96 (0.83-1.09), and that the updated model intercept was increased by 1.03 from the original model. Method 3 (intercept and regression coefficients adjusted for calibration intercept and calibration slope, respectively) showed an even greater improvement in prediction performance, R^2=0.63 (0.56-0.70) and RMSE=0.88 (0.76-0.90). The updated model increased the intercept of the original predictive model by 5.6, with individual regression coefficients times 0.74. The updated model using Method 3 with adjustments for intercept and slope showed the best predictive performance, and this was adopted in the gender-neutral updated model. (Fig.5)

Finally, the updated model was used to predict wrinkle grade in 2021 for 23 men, using 2017 as the baseline (Fig. 6). The calibration plots confirmed that the model was able to predict an individual's future wrinkles with a high degree of accuracy, although this was a visual assessment. Reviewing the images of the corner of the eyes of the subjects who were predicted with high accuracy for 2017 and 2021 shows that the wrinkle prediction model was able to detect and predict a slight but definite progression of wrinkles that was difficult to perceive by the subjects themselves. On the other hand, low prediction performance was observed in some subjects, suggesting the existence of individual differences that cannot be predicted by the current wrinkle prediction model.

3.2 Develop tools based on gender-neutral wrinkle prediction models

Fig. 7 shows a screen image of the developed digital tool from input to output. First, the user inputs self-reported values for questions regarding age and sebum content. The brightness (L* value) and redness (a* value) of the skin color are obtained from a face

image captured using the camera mounted in the mobile device. In this case, the automatic adjustment function in the AI Smart Shade Finder is used to account for differences in the brightness of the user's shooting environment. Based on this input information, the user's wrinkle profile is estimated by the wrinkle prediction model, and the user-specific wrinkle progression lines, wrinkle levels, and corresponding wrinkle images at present, in 5 years, and in 10 years are displayed. Furthermore, the risk type of the user obtained from the input information on skin brightness and sebum content are presented. The risk types are classified into light and dark skin lightness groups, and high and low sebum content groups, for a total of four risk type patterns. Finally, textual information about the individual's wrinkle profile and recommended wrinkle prevention methods is displayed. The digital tool is developed as a web application using Amazon Web Services (AWS). This makes it possible for users to easily use the application on their devices without the need to install the application. From the viewpoint of privacy protection of personal information, the user's face image is used only as input to create the information to be presented to the participants, and it is deleted immediately after creating the information.

3.3 Randomized controlled trial to verify the effect of a wrinkle prediction tool on wrinkle prevention behavior.

3.3.1 Participants

No significant differences in age (intervention group: 4.67 (95% CI, 4.47-4.86); control group: 4.62 (95% CI, 4.42-4.82)), degree of wrinkle concern, frequency of usual wrinkle behavior, or gender were detected between the intervention and control groups of study participants.

3.3.2 Effectiveness verification through the use of digital tools

Analysis of covariance revealed significant differences between the groups based on two questions related to confidence in performing anti-wrinkle behaviors (Fig. 8). Of the questions that showed a significant difference, the item "I can confidently assess the state of my own wrinkles" increased by 0.73 in the use group, while it remained at 0.25 in the non-use group. In particular, of the subjects who gave a negative response of lack of confidence before the intervention, 12 out of 23 gave a neutral or positive response with the use of digital tools, compared to only 3 out of 15 with guidebook alone. A similarly significant difference was found for the question, "I can continue to engage in wrinkle prevention actions even if I don't immediately feel the effects of my actions.", with an increase of 0.58 in the use group, whereas in the no-use group, the increase was only 0.06. In addition, when looking at subjects who responded negatively before the intervention,

9 out of 12 in the digital tool use group showed a change to a neutral or positive response compared with 2 out of 10 in the group not using digital tool. The results suggest that the use of a digital tool is more effective than digital book browsing alone in providing confidence, which is an important motivational factor for implementing wrinkle prevention behaviors, especially among subjects with low confidence.

Table 2 shows that the intervention group significantly improved in all three of the three questions on intention and in five of the seven questions on confidence before and after the intervention, while the tool-unused group significantly improved in one question on intention and in four questions on confidence. This suggests that the use of the tool was effective in improving behavioral intention and confidence. On the other hand, both the intervention group and the unused group showed significant improvement in two questions regarding the expectation of outcome, while the intervention group showed significant improvement in one question and the unused group in two questions regarding the perception of risk.

4. Discussion

This study examined how predicting an individual's precise wrinkle profile and providing information on wrinkle prevention optimized for the individual affects their wrinkle prevention strategies. Previous studies on wrinkle prevention have identified mechanisms of wrinkle development and risk factors for wrinkle progression. The relationship between wrinkle progression and skin surface condition has been studied in many cross-sectional observational studies. Skin lightness, one of the variables selected for the wrinkle prediction model in this study, has been shown to be an important factor, providing convincing support for the practical application of the wrinkle prediction model developed here. In general, prognostic models should be applicable to all populations. However, when applied to populations that clearly differ from the developed data, the predictive performance often deteriorates markedly, necessitating external validation and model updating [26,27]. In this study, our original wrinkle prediction model for a female-only population was shown to have a low prediction accuracy when applied to men, which can be expected. In a previous study comparing the progression of wrinkles by gender, it was reported that wrinkles on the forehead and at the corners of the eyes show signs of wrinkling earlier in men than in women [28]. In addition, many previous studies have reported differences in skin surface conditions, such as higher and more stable sebum levels throughout life in men compared to women [29], and darker and redder skin color in men as they age. Therefore, it was necessary to update the model by adjusting the intercept and slope using the male-gender validation population data. As anticipated, good

prediction performance was able to be achieved by increasing the intercept, suggesting that, as in previous studies, it can be considered that male participants are more likely to develop wrinkles at an earlier age than women. In addition, the fact that decreasing the regression coefficients of the wrinkle prediction model led to further improvement in prediction performance suggests that a decrease in the contribution of the skin surface condition selected as a predictor to prediction is reduced by differences in gender. This study confirms the high prediction accuracy of the updated model without the need to replace predictors. However, it is expected that enrichment of observation data on men over time and rigorous updating that takes into account gender differences in the predictors selected for the prediction model will lead to the development of a more accurate gender-neutral prediction model and support for the identification of wrinkle acceleration factors.

Cosmetic services using digital tools have been widely offered in the past to provide product recommendations based on skin diagnostics using online imaging technology and questionnaires. Most of these services are limited to explaining the user's current skin condition or recommending beauty products and services. There are also a number of highly accurate facial aging simulation applications that apply machine learning, however, these often do not attempt to understand the causes and risks of aging. The provision of information based on a wrinkle prediction model with high prediction performance employing a linear mixed-effects model in the digital tool developed in this study enabled users to understand their current and future wrinkle conditions and to select appropriate preventive methods by themselves. In the past, verification of the effectiveness of beauty-related tools has been limited to simple user tests and usage questionnaires, and few papers have reported verification results that quantitatively compare the impact on users with and without the use of user tools. In this study, by referring to recent efforts in digital health care, we confirmed that our tool significantly improved users' confidence in assessing their own wrinkle status and continuing wrinkle prevention behaviors among men and women in their late 20s to early 30s. In particular, the tool was shown to be effective at improving voluntary intention and self-confidence over psychological factors such as expectations for preventive actions and risk perception. In other words, our tool is effective in motivating consumers to voluntarily engage in wrinkle prevention behavior, not by building expectations of results or fears of serious wrinkles, but by building confidence that they can manage and reduce their own wrinkle aging by taking preventive action, and that they can choose and continue to take preventive action.

The greatest strength of this study is its application of an evidence-based framework that has been widely used for chronic diseases and public health issues to encourage

voluntary prevention on a patient-by-patient basis. The study has made it possible to quantify wrinkle profiles with large inter-individual differences, which have been difficult to predict quantitatively, using a statistical model based on data obtained from observation of individual skin conditions and wrinkle trends over time. Furthermore, the results obtained in this study are expected to maximize the results of research on the development of active ingredients and formulations for wrinkles, which has been conducted extensively in the field of cosmetics, from a practical perspective that is more in line with consumers' daily behavior.

Several issues remain to be addressed in this research. The development stage of the gender-neutral wrinkle prediction model has not been verified for all racial groups, so the target audience for the provision of information on wrinkle prevention by our tool is limited. With continued and broad data collection, we plan to improve the tool to consider not only gender differences but also racial differences. In addition, the randomized controlled trial in this study did not track whether wrinkle prevention behaviors were actually implemented. The HAPA premise distinguishes between a pre-motivational phase leading to behavioral intentions and a post-motivational phase leading to actual health behaviors [18]; the post-motivational phase of HAPA cites the need for planning on how to implement preventive behaviors in order to actually continue the behaviors. Communication between customers and counselors has long been practiced in the cosmetics industry and can be a very effective means of creating beauty action plans and encouraging continued behavior. In the treatment of chronic diseases, it has been shown that patients' dialogue with healthcare professionals to create a behavioral plan can improve adherence [30]. In the future, we expect that digital tools in cosmetic counseling will go beyond diagnosing consumers and recommending products and will become powerful partners for both consumers and counselors to confidently and repeatedly make better decisions and to develop sustainable cosmetic strategies.

5. Conclusion

This study was based on the hypothesis that the provision of personalized information based on a wrinkle prediction model will motivate consumers to take wrinkle preventive action. The results of this study were as follows, the original wrinkle prediction model updated with male-gender data showed good prediction accuracy, and the gender-neutral general extensibility of the wrinkle prediction model was confirmed. Next, we developed a web-based digital tool that can provide information based on the wrinkle prediction model by acquiring information on the skin's surface condition using image analysis technology. Finally, a randomized controlled trial using the developed digital tool

suggested that it significantly improved consumer confidence, regardless of gender, and led to improved wrinkle prevention behaviors and the continuation of these behaviors. This study suggests that providing individuals with optimized wrinkle progression and cosmetic strategies based on wrinkle prediction models can support the habituation of wrinkle prevention.

6. Conflict of Interest Statement

The authors have no conflicts of interest directly relevant to the content of this article.

7. References

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Table 1 Influence of skin condition in previous study

Variable	β coefficient	95% CI	p value
Age	0.1469	0.1230 – 0.1705	<.001
Ln[†](sebum volume)	0.7540	0.2268 – 1.2812	<.01
Skin color a*	0.3270	0.0830 – 0.5710	<.01
Means[‡][Skin color L*]	0.1654	0.0490 – 0.2814	<.01
Interaction Ln(sebum volume)×Skin color a*	-0.1044	-0.1795 – -0.0294	<.01

Table 2 Response values to the survey form

Component	Item	Group	Variation
Intention	Wrinkle prevention actions are important to me	Intervention**	0.42
		Control**	0.42
	I am able to make an effort to implement wrinkle prevention actions	Intervention*	0.36
		Control	0.17
	I intend to implement wrinkle prevention actions on a daily basis	Intervention**	0.53
		Control	0.28
Self-efficacy	I am able to choose wrinkle prevention actions confidently	Intervention**	0.74
		Control**	0.47
	I can confidently assess the state of my own wrinkles	Intervention**	0.73
		Control	0.25
	I can confidently continue with my wrinkle prevention actions	Intervention**	0.78
		Control**	0.67
	I can continue to engage in wrinkle prevention actions even if the financial burden for these actions arises	Intervention	0.19
		Control**	0.36

	I can continue to engage in wrinkle prevention actions even if I don't immediately feel the effects of my actions	Intervention**	0.58
		Control	0.06
	I would be able to explain to others the benefits and need for wrinkle prevention	Intervention	0.36
		Control	0.27
	I would be able to explain to others the proper actions to prevent wrinkles	Intervention**	1.28
		Control**	0.77
Outcome	If I continue with my wrinkle prevention actions, I can slow down the progression of my own wrinkles	Intervention	0.01
		Control	0.02
	If I continue with my wrinkle prevention actions, I can maintain my youthful appearance	Intervention	0.18
		Control	-0.02
	If I continue with my wrinkle prevention actions, it will lead to a better future for myself	Intervention**	0.52
		Control**	0.37
	Regardless of the progression of my wrinkles, if I continue with my wrinkle prevention actions it will lead to a better future for myself	Intervention	0.13
		Control	0.14
	If I continue to take action to prevent wrinkles, the psychological distress related to wrinkles can be reduced	Intervention*	0.37
		Control**	0.32
Risk	If I don't take action to prevent wrinkles, severe wrinkles will appear prematurely	Intervention**	0.59
		Control**	0.61
	If serious wrinkles appear, it is difficult to improve the wrinkles that have appeared	Intervention	0.15
		Control	0.16
	If I don't take action to prevent wrinkles, I will experience increased psychological distress from wrinkles in the future	Intervention	0.13
		Control**	0.42

Variation of the mean before and after the intervention *p<.05, **p<.01

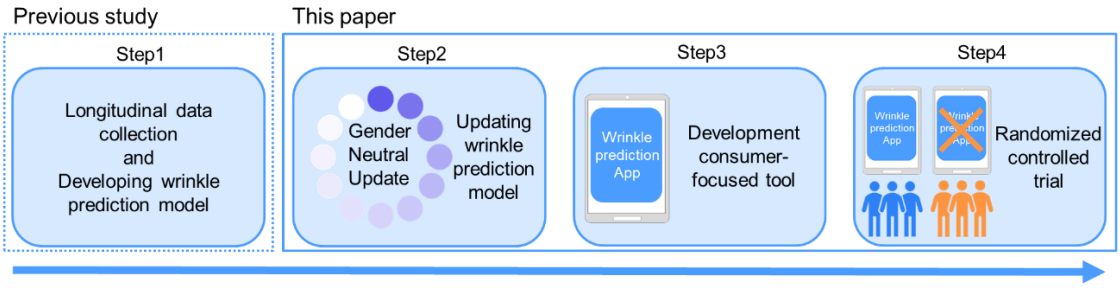


Fig. 1 Comprehensive wrinkle prediction model study

$$
\begin{aligned}
&Wrinkle\ grade_i \\
&= 0.1469 \times age \\
&\quad + 0.7540 \times ln(sebum) \\
&\quad + 0.3270 \times skin\ color\ a^* \\
&\quad + 0.1654 \times mean[skin\ color\ L^*] \\
&\quad - \ 0.1044 \times [ln(sebum) \times skin\ colora^*] \\
&\quad -15.90 + b_{0,i} \\
&b_{0,i} \sim N(0, 0.4847)
\end{aligned}
$$

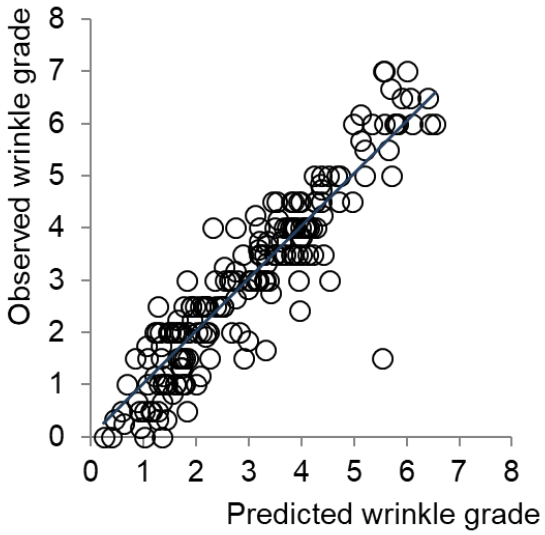


Fig. 2 Developed wrinkle prediction model and calibration plots

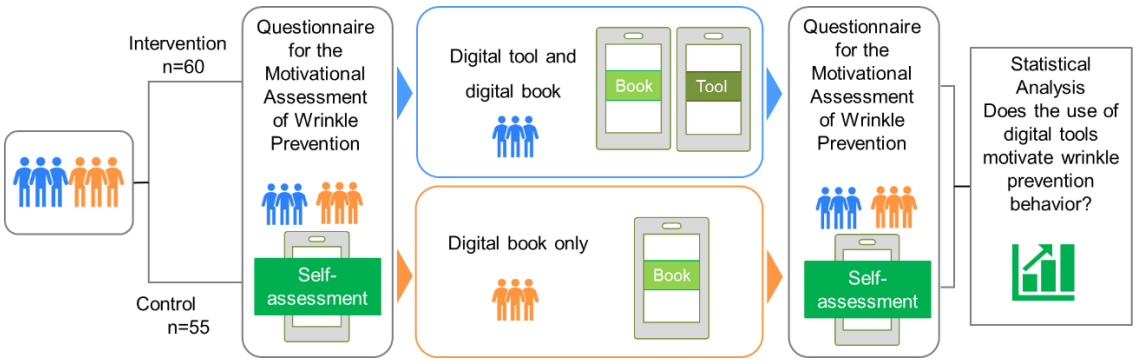
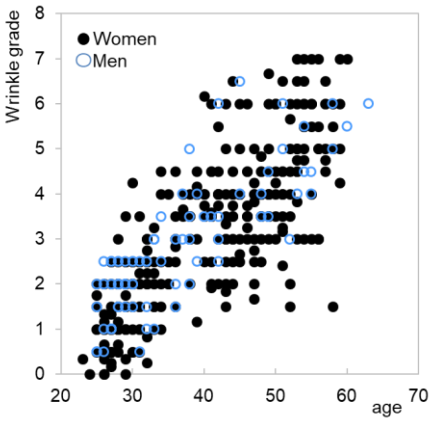


Fig. 3 Randomized controlled trial to verify the usefulness of a digital tool based on a wrinkle prediction model

	Development data for women (n=48)	Validation and update data for men (n=80)
Follow up	7 years	1 year
Age	40.56 (39.42-41.69)	35.91 (33.65-38.18)
Wrinkle grade	3.18 (2.99-3.37)	2.72 (2.40-3.04)
Ln(sebum volume)	3.05 (2.91-3.19)	3.05 (2.83-3.26)
Skin color L*	64.92 (64.62-65.23)	60.14 (59.40-60.89)
Skin color a*	6.84 (6.65-7.03)	8.98 (8.71-9.27)



Data are presented as means (95 % CI)

Fig. 4 Characteristics of developed and updated data

Updating method	R squart (95% CI)	RMSE (95% CI)
No adjustment	0.03 (0.00-0.23)	1.41(0.93-1.89)
Intercept α	0.55 (0.46-0.64)	0.96 (0.83- 1.09)
α + calibration slope $\beta_{overall}$	0.63 (0.56–0.70)	0.88 (0.76–0.90)

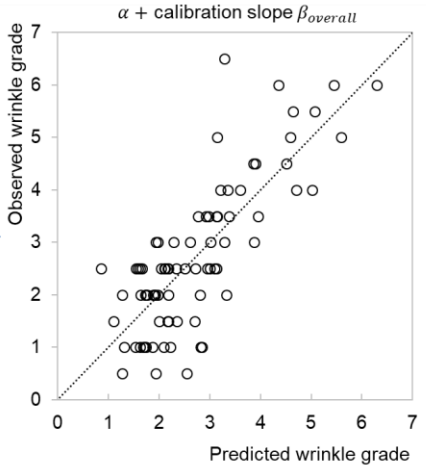
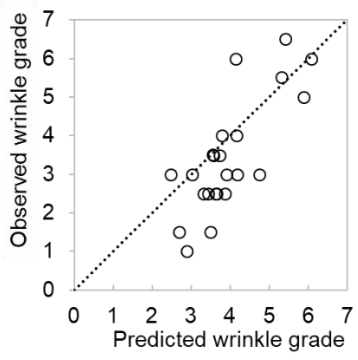


Fig. 5 Model settings and calibration plots for original and updated models



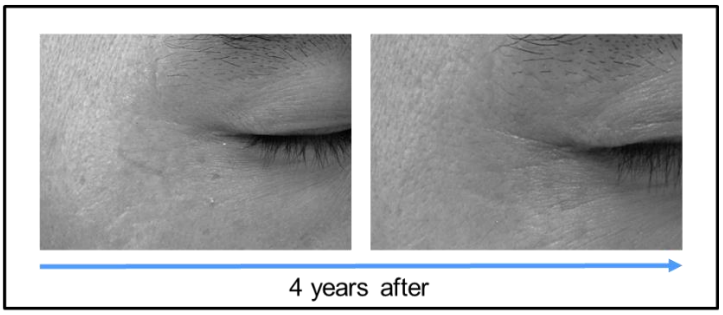


Fig. 6 Calibration plot of predicted 2021 wrinkle grade values based on 2017 and highly accurately predicted subject eye images

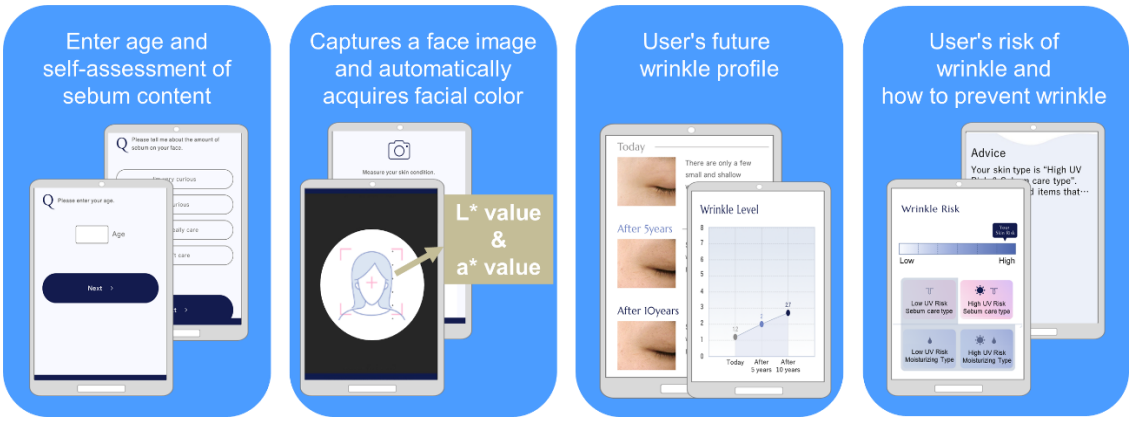


Fig. 7 Digital tools developed based on the wrinkle prediction model

Item	Group	Before	After
I can confidently assess the state of my own wrinkles*	Intervention	3.80 (3.46-4.14)	4.53 (4.21-4.86)
	Control	4.35 (3.89-4.80)	4.60 (4.19-5.01)
I can continue to engage in wrinkle prevention actions even if I don't immediately feel the effects of my actions**	Intervention	4.60 (4.30-4.90)	5.18 (4.89-5.47)
	Control	4.98 (4.59-5.38)	5.04 (4.65-5.42)

Data are presented as means (95 % CI) *p<.05, **p<.01

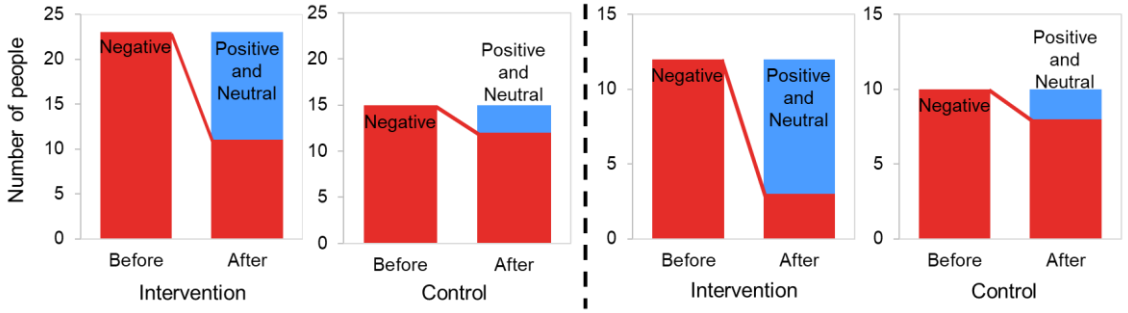


Fig. 8 Group Comparison by Analysis of Covariance & Changes in Negative Respondents
left: I can confidently assess the state of my own wrinkles
right: I can continue to engage in wrinkle prevention actions even if I don't immediately feel the effects of my actions