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Age-related changes in cheek skin movement: A case study of Japanese women

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Abstract

Background: The majority of conventional studies on skin aging have focused on static conditions. However, in daily life, the facial skin we encounter is constantly in motion due to conversational expressions and changes in facial expressions, causing the skin to alter its position and shape, resulting in a dynamic state. Consequently, it is hypothesized that characteristics of aging not apparent in static conditions may be present in the dynamic state of the skin. Therefore, this study investigates age-related changes in dynamic skin characteristics associated with facial expression alterations.

Methods: A motion capture system measured the dynamic characteristics (delay and stretchiness of skin movement associated with expression) of the cheek skin in response to facial expressions among 86 Japanese women aged between 20 and 69 years.

Results: The findings revealed an increase in the delay of cheek skin response to facial expressions ($r = 0.24$, $p < 0.05$) and a decrease in the stretchiness of the lower cheek area with age ($r = 0.60$, $p < 0.01$). An increasing variance in delay and stretchiness within the same age group was also observed with aging.

Conclusion: The findings of this study revealed that skin aging encompasses both static characteristics, such as spots, wrinkles, and sagging, traditionally studied in aging research, and dynamic aging characteristics of the skin that emerge in response to facial expression changes. These dynamic aging characteristics could pave the way for the development of new methodologies in skin aging analysis and potentially improve our understanding and treatment of aging impressions that are visually perceptible in daily life but remain unexplored.

KEYWORDS
aging, delay, facial skin, skin movement, stretchiness

1 | INTRODUCTION

The facial skin undergoes various changes with aging, yet traditional research on facial aging has primarily focused on the skin in a "static" state, such as a neutral expression. Reports predominantly detail changes in coloration and morphology associated with aging, including yellowing, and browning of the skin tone, increased spots,[1–5] and morphological changes such as an increase in skin surface irregularities due to wrinkles and sagging.[6–14] In response to these changes, individuals have sought prevention through skincare, optical concealment via makeup, and improvements through massage or cosmetic surgery.

In contrast, most faces encountered in daily life are in a dynamic state through expressions and conversation. Therefore, the impression others have of us is not solely based on static features. Research on the impact of facial movements on participative age impressions has shown that in individuals over 50, the impression of age given to others increases with changes in expression, particularly judged from the cheeks.[15] Additionally, studies on facial age estimation systems report that systems based on videos, incorporating dynamic information, show improved age estimation accuracy compared with systems based only on static facial images.[16] Hence, these studies suggest that some dynamic visual characteristics of the skin change with aging.

The skin covering the face is a multilayered structure with different mechanical properties in the subcutaneous tissue, dermis, and epidermis, where the extracellular matrix components undergo qualitative and quantitative changes with age, leading to reduced viscoelasticity.[6–14] During facial expressions, the movement of deep facial muscles is transmitted to the face's surface through layers of skin with distinct properties. To discuss the dynamic characteristics of the skin surface, it is essential to consider the intrinsic movement properties of the skin.

Previous studies focusing on skin movement properties include Kuwazuru et al.'s investigation of wrinkle formation because of skin contraction movements, such as those at the corners of the eyes.[17] It was reported that the internal mechanical properties of the skin contribute to wrinkle formation during skin contraction based on a model simulating the multilayered structure of the skin and the finite element method with skin internal properties as variables. They also reported age-related changes in transient wrinkle formation when the skin at the corners of the eyes is forcibly contracted. However, age-related changes in more macroscopic movements and stretching of the cheek skin, such as those accompanying emotional expressions, remain unclear.

Hence, this study aimed to assess the movement properties of the cheek skin in response to expression changes. Facial expressions were simplified as vertical stretching movements, with standardized intensity and timing among all participants. The skin's movement properties include the time taken to respond to the force pulling the cheek skin downward (delay) during vertical jaw movement and the amount of deformation in stretching and shrinking (stretchiness). Delay is defined as the extent to which the skin surface does not follow the jaw's downward movement during the opening, while stretchiness is measured as the stretching ratio of the upper and lower cheek skin, investigating age-related changes in these parameters.

For measuring the movement properties of the skin surface, representative methods include the motion capture method,[18,19] involving the direct placement of markers or sensors at measurement sites to obtain coordinates, and the optical flow method,[20–22] indirectly measuring based on skin imaging. In this study, considering the face as a three-dimensional object and the subtle dynamic characteristics associated with aging occurring during expression changes, the motion capture method was adopted. This method can account for information in the depth direction near contours, such as the cheeks, and enhance measurement accuracy by correcting the rigid body movement of the head.

2 | METHODS

2.1 | Participants

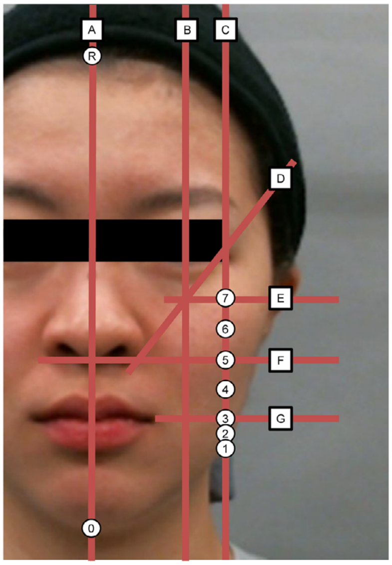
Ninety Japanese women, with ages ranging from 20 to 69 years (mean age 49.19 ± 12.90), participated in the experiment. The study received approval from the Ethics Committee of POLA Chemical Industries Inc., adhering to the Declaration of Helsinki (Review Nos. 2015-J-087, 2016-I-007, 2016-I-140), and written consent was obtained from all participants. All participants have not imposed any restrictions on the use of skincare products during the recruitment phase. However, they all washed their faces and then underwent acclimatization for 20 min in a constant temperature and humidity room (room temperature: 20 ± 2°C, humidity: 50% ± 10%) before performing the measurement experiment when participating in this study at the venue.

2.2 | Tracking marker placement

To monitor facial skin movement using cameras, tracking markers were strategically placed (Figure 1). To exclusively measure the dynamic characteristics of the cheek skin associated with changes in facial expression, a reference point (R) was positioned on the upper hairline of the forehead center to eliminate the influence of rigid head movements. Additionally, contrast point (0) was located at the chin's Menthone, serving as a benchmark for expression changes. Seven points were aligned on the vertical line from the corner of the eye to gauge the motility of the left cheek skin. White foam beads, approximately 4 mm in diameter, were utilized as tracking markers. In this study, we preliminarily verified skin movement caused by facial expression changes and measured the left cheek of all participants without considering the left-right difference of the face.

2.3 | Motion capture recording

The motion capture system Move-tr/3D used high-resolution C-MOS color cameras LB-GV140, multi-image input software Capture-NX Ver2.96, and a SAS-connected continuous high-speed writing HDD system HDD-EXViewer Ver2.60 (all from Library, Tokyo, Japan). The sampling rate for the motion analysis was 30 Hz, and the maximum measurement error was 0.62 mm. Participants were seated in front of the camera, as shown in Figure 2, and were recorded while performing predetermined facial movements. The instruction was to transition from a neutral expression to a vertical stretching expression (opening the mouth wide and pronouncing "Ah," as shown in Figure 3). The timing of these expression changes was synchronized using a metronome, with the expression changing from neutral to vertical stretching every



Reference lines	Description of reference lines
A	Midline
B	Vertical line through the center of the eye
C	Vertical line from the outer corner of the eye
D	Tangent line from the outer corner of the eye to the nostril
E	Parallel line from the intersection of line B and line D
F	Parallel line at the subnasale
G	Parallel line at the mouth corner

Markers	Description of markers
R	Intersection of line A and the hairline
0	Soft tissue menthone
1	Intersection of line C and the jawline
2	Midpoint between marker 1 and marker 3
3	Intersection of line C and line G
4	Midpoint between marker 3 and marker 5
5	Intersection of line C and line F
6	Midpoint between marker 5 and marker 7
7	Intersection of line C and line E

FIGURE 1 Tracking marker placement. The photograph shows the locations of markers used to obtain the coordinates of specific locations by the motion capture method. On the highest part of the forehead, marker R showing the reference point was fixed. No. 0 marker was put on the bottom of the chin as the contrast point to the points of the cheek, and No. 1 to 7 markers were fixed on the locations from the lowest to highest parts of the left cheek.

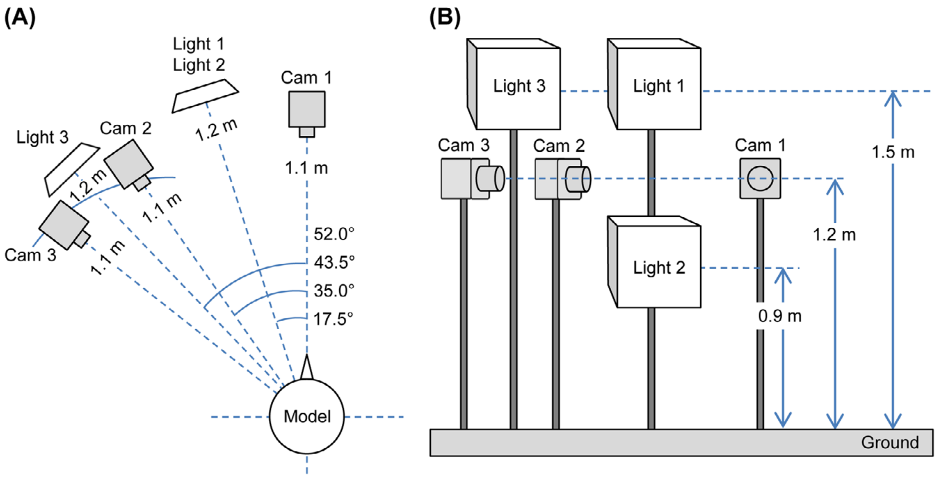


FIGURE 2 Equipment layout of motion capture cameras. Dynamically changing facial expressions were filmed using a digital video camera from three different directions. (A) Upper view of equipment layout. (B) Front view of equipment layout.

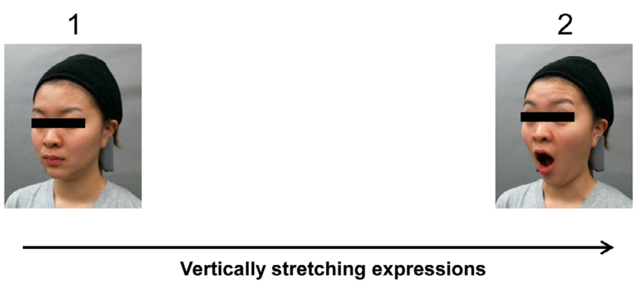


FIGURE 3 Facial expression tracking by the motion capture system. Photograph 1 shows a neutral facial expression; photograph 2 shows lowering chin with opening mouth expression. The facial expression was exchanged in a second. The long arrow over the facial photographs shows the stream of time.

second. The participants were directed to maximize expression intensity, and both the timing and strength of expression were thoroughly trained before the experiment.

2.4 | Data analysis

2.4.1 | Participant screening

Participant data, in which skin movement measurement was challenging, were excluded based on the following rationale. When expressing vertical stretching movement from a neutral expression, it was assumed that the cheek markers move sequentially from the lower to the upper. Therefore, the regression coefficient—plotting each cheek

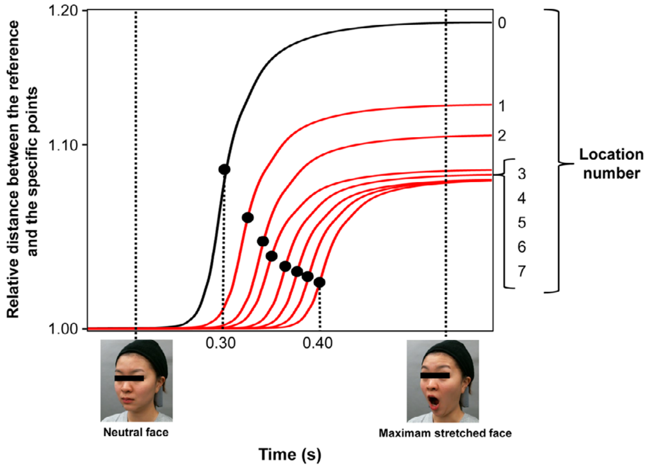


FIGURE 4 The time-courses among markers for analyzing facial movement speeds. The graph shows the time-courses of distances between markers No. 0 to 7. The x-axis represents elapsed time, calculated from the number of frames in a video file captured by the motion capture camera. The y-axis shows the relative distances between the reference point (R) and markers No. 0 to 7. These relative distances were calculated by dividing the distances on the expression faces by those on the neutral faces. The highest speeds of changes in distances between the reference and specific points were determined by differentiating the time-course curves, as indicated by closed circles (●) in the graph. The time in the highest speeds between the bottom of the chin, represented as No. 0, and the cheeks, marked as No. 1 to 7, was identified as delays between the movements of the chin and specific locations on the cheek.

marker number (points 1 to 7 in Figure 1) on the horizontal axis and the time each point reaches its highest speed on the vertical axis—should be positive. If movements, such as blinking near the eyes, occur during expression, the regression coefficient might become negative. Hence, participant data for which regression coefficients were negative due to such influences were excluded.

2.4.2 | Delay of the cheek skin movement

The delay time of the cheek skin was calculated as the time difference between the moment the contrast point (point 0 in Figure 1) reached its highest speed and when each point on the cheek (points 1 to 7 in Figure 1) did so during the vertical stretching expression from a neutral state (Figure 4). Figure 5 shows the relationship between the delay time and points 1 to 7. The regression coefficient (slope) obtained from each point's delay time and marker position was defined as the "delay amount" of each participant's cheek movement.

2.4.3 | Stretchiness of the cheek skin

Focusing on cheek skin stretchiness during expression, the rate of change in the distance of the cheek skin (points 1–7 in Figure 1) from its neutral state at the moment the distance of movement between

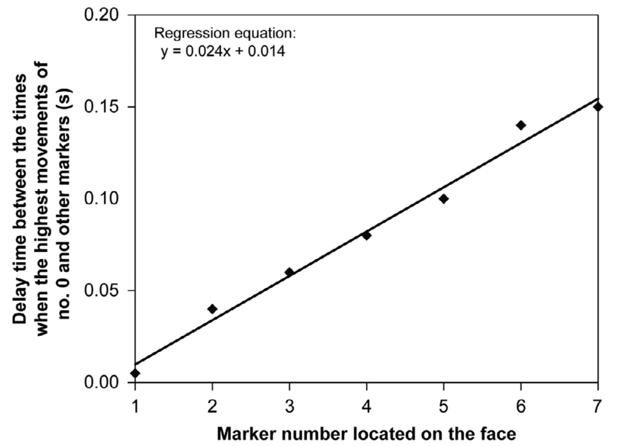


FIGURE 5 Example of the relationship between the delay times between the highest movement at No. 0 marker and those at No. 1 to 7 markers, and the location of No. 1 to 7 markers. This graph shows an example of the delay time between the highest movements of the markers. A straight line, representing a regression line, was calculated from the delay times and markers' locations. The equation in the graph, $y = 0.024x + 0.014$, denotes the regression equation. Here, "0.024" indicates the regression coefficient (slope), suggesting the degree of delay. This coefficient shows that the delay times linearly increase with the growing distance from marker No. 0.

the reference point (point R in Figure 1) and the benchmark (point 0 in Figure 1) was maximal during the vertical stretching expression was defined as the "stretchiness" of skin movement in response to facial expression. At this time, the facial cheek area was divided into upper cheek (points 1–4 in Figure 1) and lower cheek (points 4–7 in Figure 1), and the rate of change in the distance of the lower cheek compared with the overall cheek movement during expression, namely the "stretchiness of the lower cheek," was measured.

2.4.4 | Statistical analysis

The relationship between each participant's delay and stretchiness amounts and their actual age was examined using Pearson's product-moment correlation analysis. Statistical analyses were conducted using SPSS version 25.0 (IBM, Armonk, NY, USA).

3 | RESULTS

3.1 | Participant screening

Participants with skin movement data difficult to measure during the specified expressions, such as blinking effects, were excluded. Four participants (all in their 60s) showing negative regression coefficients indicating eye muscle movement were excluded. The analysis comprised 86 participants (mean age 49.29 ± 12.99 years). Sample size determination utilized GPower 3.1.9.7 software,[23] employing default values, revealing that 84 participants were needed for the correlation

TABLE 1 Participant demographics.

Age group (Years)	N.	Mean (Years)	S.D. (Years)
20–29	10	25.50	3.31
30–39	11	36.09	1.81
40–49	17	44.18	2.79
50–59	24	54.13	2.54
60–69	24	64.04	2.40

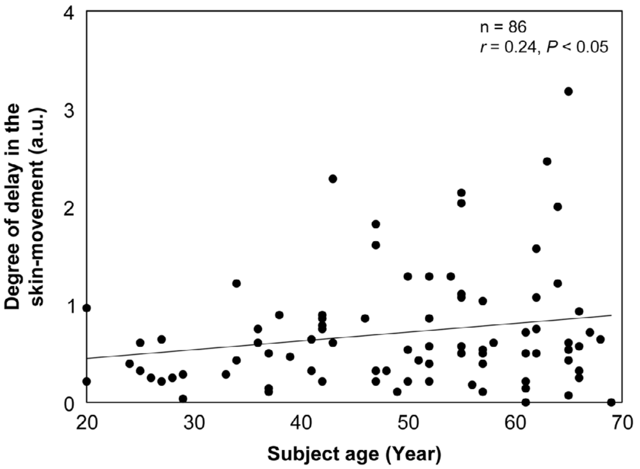


FIGURE 6 Effect of age on the degree of delay in the cheek skin movement. This graph presents the relationship between the degree of delay on the y-axis, corresponding to the slope shown in Figure 5, and the age of the models ($r = 0.24$, $p < 0.05$). The straight line is the regression line, $y = 0.009x + 0.2672$, indicating that the degree of delay increases with advancing age.

TABLE 2 Variance in delay amount by age group.

Age group	20s	30s	40s	50s	60s
Variance in the delay amount	0.069	0.110	0.365	0.296	0.624

analysis (effect size $F = 0.30$, $\alpha = 0.05$, power = 0.80). Table 1 displays the distribution of participants included in the analysis.

3.2 | Delay of the cheek skin movement

Figure 6 presents a scatter plot depicting the relationship between each participant's delay amount and actual age. Correlation analysis revealed a weak correlation ($r = 0.24$, $p < 0.05$), suggesting an increase in delay amount with aging. Furthermore, a trend of increasing variance in delay amount within the same age group was observed with aging (Table 2).

3.3 | Stretchiness of the cheek skin

The analysis results of the "stretchiness change rate of the lower cheek" in proportion to the total stretching movement of the cheek skin during expression for each participant are displayed in Figure 7. The results confirmed that the elongation rate of the lower cheek skin in response to overall cheek stretching decreased with aging ($r = -0.60$, $p < 0.01$). A trend of increasing variance in stretchiness within the same age group was also observed with aging (Table 3).

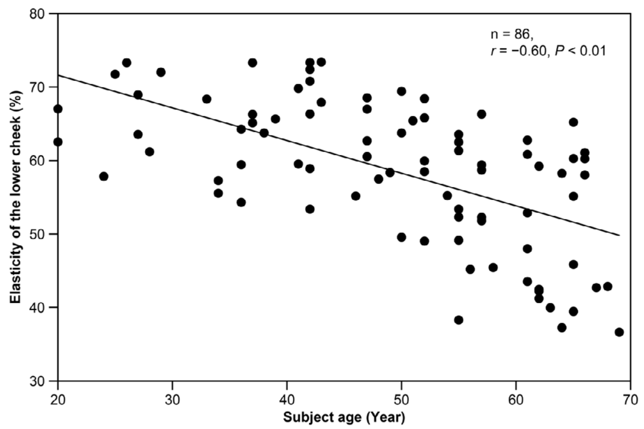


FIGURE 7 Effect of age on the stretchiness of the lower cheek skin movement. This graph illustrates the association between the stretchiness of the lower cheek skin movement on the y-axis and the age of the models ($r = -0.60$, $p < 0.01$). The straight line is the regression line, $y = -0.0044x + 0.8051$, indicating that the stretchiness of the lower cheek decreases with advancing age.

TABLE 3 Variance in stretchiness by age group.

Age group	20s	30s	40s	50s	60s
Variance in stretchiness	0.054	0.058	0.066	0.087	0.103

4 | DISCUSSION

This study focused on analyzing the dynamic characteristics of the skin, specifically the delay and deformation amount of cheek skin during mouth opening movements in response to the downward movement of the jaw, as parameters of skin dynamics. We examined how these parameters change with aging.

The findings confirmed that the delay in cheek skin movement in response to facial expression changes increases with aging. This suggests a longer response time to the downward movement during mouth opening, indicating the aging-induced property changes were manifested in the viscosity (slow deformation in response to external force), not in the elasticity (instant deformation in response to external force) in the skin, which possesses both properties. This aligns with existing reports using the Cutometer in skin mechanics, indicating that the viscoelastic parameter R6 (the ratio of time-dependent deformation Uv to instantaneous deformation Ue when the skin is suctioned) increases with aging,[24] signifying a decrease in skin viscoelasticity.[6–14] Facial skin aging results from natural aging processes and photoaging primarily due to sun exposure. Photoaging, contributing to 80% of skin aging, involves changes in tissue properties such as solar elastosis and a loss of skin elasticity due to alterations in dermal elastic fibers.[11,12] The observed delay in skin surface movement in this study is likely attributable to changes in the internal properties of the skin, such as viscoelasticity, stemming from histological changes in skin structures primarily caused by photoaging.

There was also a decrease in cheek skin stretchiness, particularly in the stretchiness change rate of the lower cheek, with aging. This localized stretchiness decline may be attributed to increased sagging of the cheek area, primarily due to aging and, specifically, photoaging.[9,10] The measured area is known to be susceptible to significant sagging.[25] While the upper cheek is connected to facial muscles via ligaments, the lower cheek hangs from upper cheek ligaments.[26–28] It is believed that the increased degree of sagging in these areas causes the movement of the lower cheek skin surface to become independent of the stretching movement of facial muscles, resulting in a decrease in the stretchiness change rate of the lower cheek.

Moreover, both delay and stretchiness scores exhibited an increase in variance with age. This likely reflects the diverse degrees of photoaging among individuals. The risk of photoaging varies significantly based on factors such as residential sunlight exposure, work habits, and lifestyle choices. Measures against photoaging, such as sunscreen use, sun umbrellas, and hat-wearing, also vary among individuals. The increased variance in delay and stretchiness with aging observed in this study likely mirrors these individual differences in the degree of photoaging.

The results not only unveiled static aging features of the skin, such as spots, wrinkles, and sagging, traditionally emphasized in studies but also dynamic skin aging linked to changes in facial expressions. Previous research on the impact of dynamic and static faces on perceived age reported that dynamic faces are perceived as older with increasing age of the participants.[15] The dynamic aging features identified in this study may contribute to this perceived age. If correct, these dynamic aging features could inform strategies for enhancing skin properties through skincare or optically concealing the movement state of the skin surface with makeup. In particular, skin care, moisturizing, and care with active ingredients would effectively maintain and improve skin viscoelasticity. As makeup, the formulation of powder that homogenizes the appearance of the skin surface by light scattering, which becomes a factor that makes the mobility of the skin, such as transient wrinkles caused by facial expressions noticeable, is considered to be effective. Additionally, with the increased prevalence of web conferencing in daily life due to the COVID-19 pandemic, controlling these dynamic features could be technologically implemented to appear more youthful during screen-based face-to-face communication by correcting the delay and stretch changes of the skin.

Finally, future research directions are discussed. A limitation of this study is that the facial movements measured were only in the vertical direction of the left cheek. This study simplified movements to vertical stretching expressions in the left cheek for ease of measurement. However, in daily life, more complex muscle contractions occur, such as smiling, which involves spreading the mouth outward and upward. Furthermore, the face is not strictly symmetrical, and the asymmetry increases with aging.[29–31] The facial mobility also becomes asymmetrical, which affects the perceived age of the face.[32] Additionally, skin tension is not uniform, and mechanical anisotropy due to the orientation of dermal collagen and elastin has been reported.[33,34] Therefore, future studies should consider a variety of facial expressions and analyze the effects of skin movement direction, the left-right difference, and anisotropy on elasticity to provide a more accurate reflection of facial and skin conditions.

5 | CONCLUSION

In daily life, faces are in constant motion due to conversation and changes in expression, leading the skin to dynamically change its position and shape. Traditional research on skin aging, however, has predominantly focused on a limited condition—the skin of a neutral, or static, face. Therefore, this study aimed to investigate age-related changes in the dynamic characteristics of the skin associated with changes in facial expressions. The results revealed that with aging, there is an increase in the delay of cheek skin response to facial expressions and a decrease in the stretchiness of the lower cheek area.

The findings clarified that dynamic skin aging exists, complementing static aging characteristics such as spots, wrinkles, and sagging, which have been traditionally studied. These dynamic aging characteristics could pave the way for new methods to analyze skin aging, potentially enhancing our understanding and treatment of visually perceptible aging impressions in daily life that have remained largely unexplored.

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CONFLICT OF INTEREST STATEMENT

M.K., J.Y., M.K., and K.M. were employees of POLA Chemical Industries, Inc.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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