Optimization of the hanger reflex (I): Examining the correlation between skin deformation and illusion intensity

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Abstract
One method of presenting a pseudo-force sensation is based on a phenomenon called the hanger reflex, in which placement of a wire hanger on the head induces involuntary head rotation. The main cause of this phenomenon is considered to be a pseudo-force sensation generated by lateral displacement of the skin via skin compression. However, the relationship between the physical amount of skin displacement and the strength of the illusion has not been thoroughly investigated, impeding optimization of a device that elicits the hanger reflex. As a first step towards developing an optimized hanger reflex device, we describe a method for measuring the amount of skin deformation during the occurrence of the hanger reflex, by using optically observable artificial skin. We report the correlation between deformation of the artificial skin and head rotation angle, which had previously been reported only qualitatively.

Keywords: Hanger Reflex · Illusion · Skin stretch

1 Introduction

Researchers have proposed a number of methods for presenting a force sensation to users via illusory phenomena [1][2][3][4]. One method for presenting a pseudo-force sensation involves a phenomenon called the hanger reflex, in which placement of a wire hanger on the head elicits involuntary head rotation (Figure 1)[5]. The direction of tangential skin deformation generated by compressing two points on the head has been related to the direction of head rotation (Figure 2)[7]. A similar phenomenon has been reported in the wrist, waist, and ankle [8][9].

Although the direction of lateral deformation of the skin coincides with the direction of the hanger reflex, the amount of lateral displacement of the skin has not been fully examined in terms of the strength of the hanger reflex. For example, whether the "total amount" or "peak value" of lateral displacement contributes to the phenomenon has not been clarified. This information is considered to be essential to the optimal design of a hanger reflex device.

In this paper, as a first step in developing an optimized hanger reflex device, we tested a method for measuring the amount of deformation of skin on the head during the hanger reflex, by using optically observable artificial skin. We report the correlations between the skin deformation, head rotation angle, and subjective strength of the hanger reflex.

Figure 1. Hanger Reflex [7]

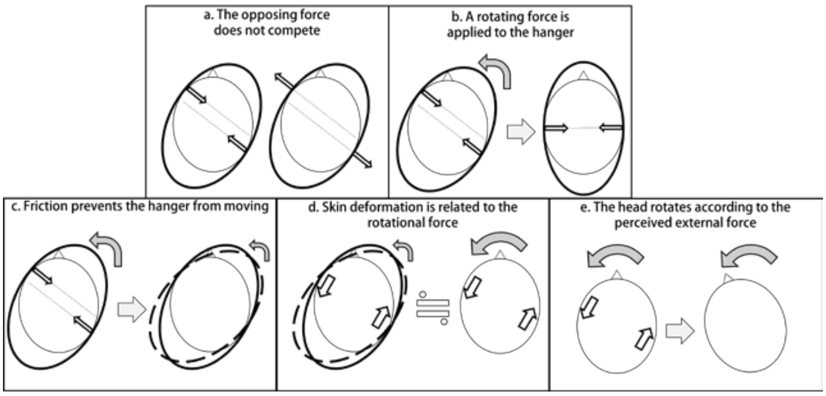


Figure 2. Mechanism of hanger reflex induced by skin shearing [7]

2 System configuration

It is difficult to observe deformation of the skin on the head during the hanger reflex because the affected skin may be obscured by the wire hanger or hair of the participant. To address this issue, we constructed a transparent model of a cross-section of a human head. The model was composed of a hard "skull" and soft "skin". We placed optical markers on the "skin" to enable observation from inside the model.

2.1 Transparent skull model

We used a mold gauge (Shinwa measurement) to measure a cross-section of the head immediately above the ears of the subject (the author) (Figure 3). We also used this head position to measure the hanger reflex. We created a transparent 2D skull by reproducing the shape of the head using an acrylic plate (10 mm thick) (Figure 4). We then cut the interior to enable visual observation from inside the model.

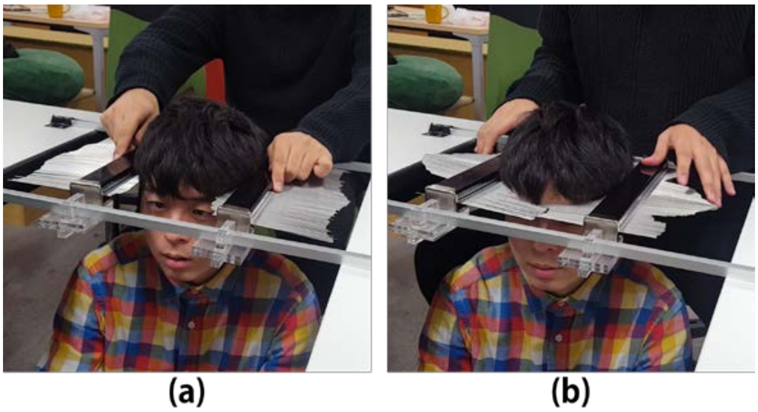


Figure 3. Measurement of head cross-section:
(a) setting, (b) measurement

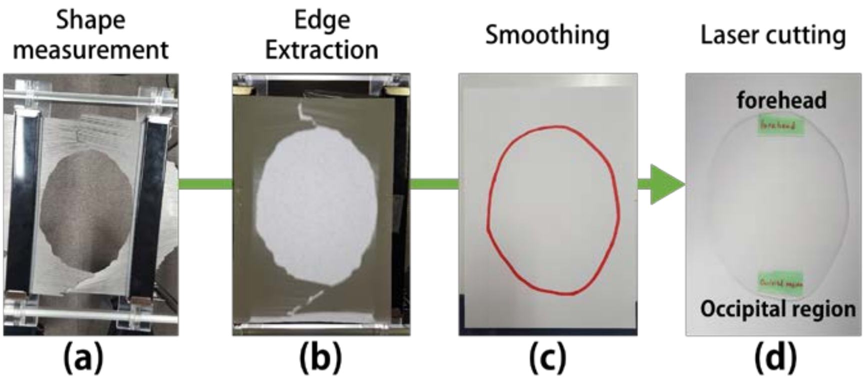


Figure 4. Reproduction of the head cross-section:
(a) Measuring the head shape, (b) Edge extraction of the head shape, (c) Smoothing the extracted edge, (d) Cutting the acrylic plate.

2.2 Transparent skin

We used an optical marker tracking method to observe skin deformation from inside the head model, which was employed in several robotic skin projects [10][11][12]. We adhered four sections of transparent gel containing markers (lead balls, 1 mm in diameter, arranged in 3 mm intervals) (Figure 5) to the outer periphery of the transparent skull model (Figure 6). The thickness of the gel was 5 mm, and the marker was buried at a depth of 1 mm from the surface.

The hardness and thickness of the marker-containing gel was not an accurate representation of human skin. However, based on our experience with the hanger reflex, we feel that the shape of the head has a stronger impact on whether or not the hanger reflex will occur (subjects who are less likely to experience the hanger reflex have a more spherical vs. ellipsoidal head shape) [7]. Thus, we speculated that by reproducing the shape of the skull we could capture the essential phenomenon caused by the hanger reflex.

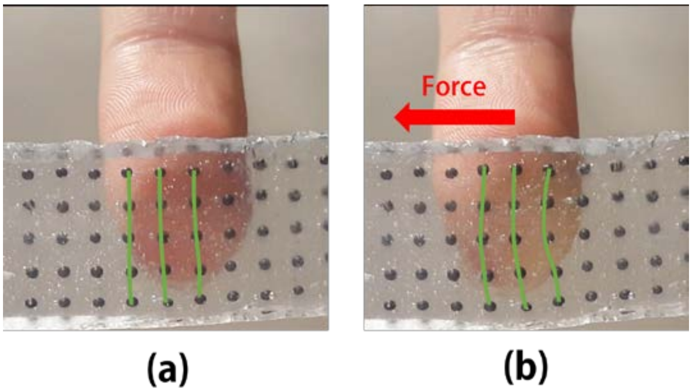


Figure 5. Deformation of marker-containing gel in the lateral direction (a) without force (b) with force

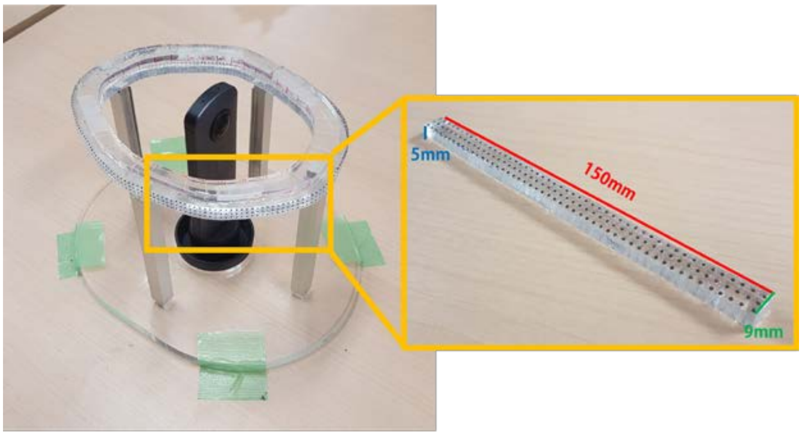


Figure 6. Transparent head model

3 Experiment 1

In this experiment, we assessed the amount of gel deformation caused by attaching a wire hanger to the head model. The hanger reflex is known to be strongest when the longest side of the wire hanger contacts the front temporal region of the head [5]. Thus, we set the center of the forehead on the model as 0 °, and calculated the angle coordinates in a clockwise direction (e.g. 90 ° was located around the right ear and 270 ° was around the left ear). We measured skin (gel) deformation that occurred when the longest side of the hanger contacted the model at an angle of 10 ° to 90 ° and 270 ° to 350 °, in 10 ° intervals.

For observation, we used a 360 ° camera (Ricoh Theta V), and recorded a 360 ° video from inside the transparent skull. The contact position was indicated by a red marker placed at the center of the long side of the wire hanger. Since the wire hanger changes shape during the procedure, we used a new wire hanger for each trial.

The experiment was conducted using the following procedure.

1. Start filming with the camera prior to attaching a wire hanger.
2. Attach a wire hanger at the designated angle.
3. Record for several seconds and then stop recording.

3.1 Experimental results

To analyze deformation of the gel, we compared images with the hanger vs. without the hanger (Figure 7). First, the two images were overlapped. Next, we drew vertical lines every 10 °, and examined any horizontal displacement of the upper and lower markers. We used the three markers closest to the lines for measurement, and calculated the average displacement. The precision of the measurement, conducted via visual observation, was within 1 pixel. This corresponds to 0.18 °, i.e., a skin displacement of 0.25 mm at the front of the head.

The results are shown in Figure 8 and Figure 9, which show a wire hanger attached to the right front temporal (contact position 10 ° to 90 °) or left front temporal (contact position 270 ° to 350 °) region, respectively. The vertical axis shows skin deformation (pixels), and the horizontal axis shows head position in degrees.

The 360 ° camera could record stable images for objects that were more than 10 cm away from the lens. Accordingly, we were unable to perform some measurements, as the temporal regions of the model were less than 10 cm from the lens. However, these regions were distant from the contact positions of the wire hanger, and so we did not expect to see movement in these areas.

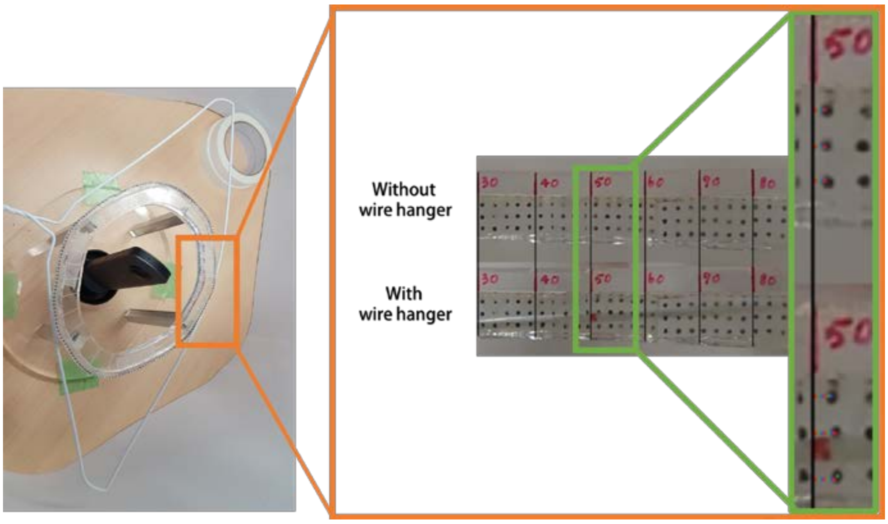


Figure 7. Amount of gel deformation

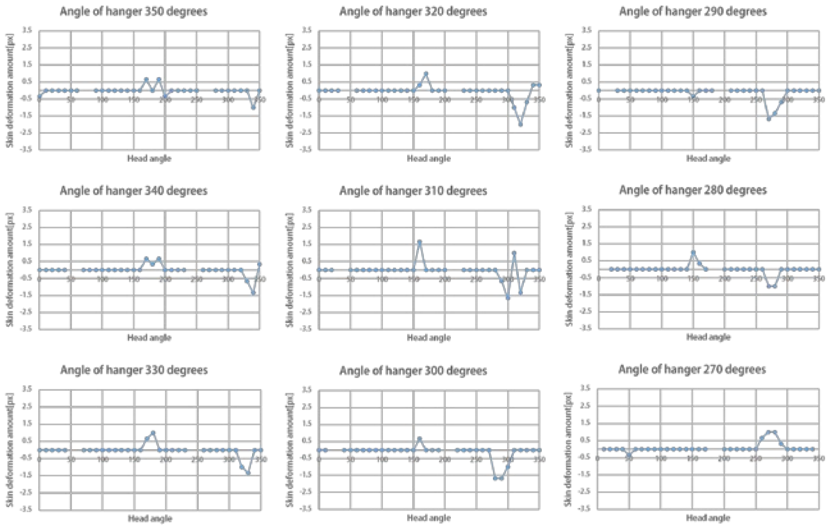


Figure 8. Gel deformation elicited by a wire hanger placed on the right front temporal region of a head model

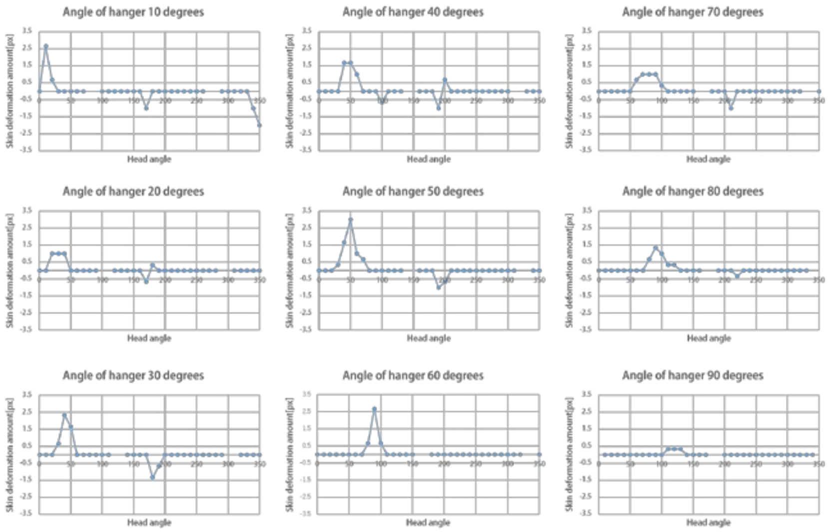


Figure 9. Gel deformation elicited by a wire hanger placed on the left front temporal region of a head model

4 Experiment 2

In this experiment, we measured the strength of the actual hanger reflex.

We used a swimming cap to secure the hair on the subject's head such that the wire hanger pressed only the skin of the forehead and did not pass through the hair. We used an acrylic plate (2 mm thick) hollowed out in the shape of the head of the subject. The plate was engraved with lines in 10 ° increments. By placing the plate on the subject's head above the swimming cap, we were able to unify the angle of the wire hanger with the angles used in Experiment 1. We used a new wire hanger for each trial.

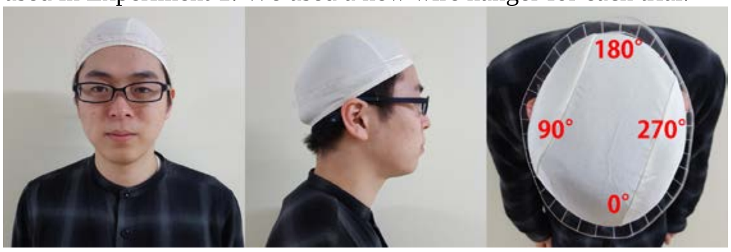


Figure 10. Subject setup

The subject was a healthy male (the author). He wore a wire hanger at multiple positions from 10 ° to 90 ° and from 270 ° to 350 ° , as in Experiment 1. The positions were 10 ° apart. He was instructed not to resist the perceived hanger reflex. The experiment was carried out in the following procedure.

1. The subject closed his eyes, and the experimenter attached a wire hanger at the designated angle.
2. The experimenter measured the angle to which the subject rotated his head from above using a digital protractor.
3. The subject was asked to report the subjective strength of the hanger reflex by drawing a line on a visual analog scale (Figure 11). The responses were quantified as +50 (right direction) and -50 (left direction).

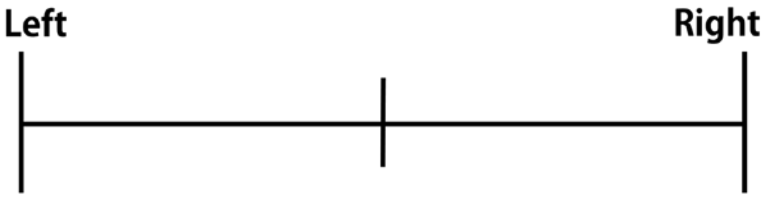


Figure 11. Visual analog scale for reporting subjective stength of the hanger reflex

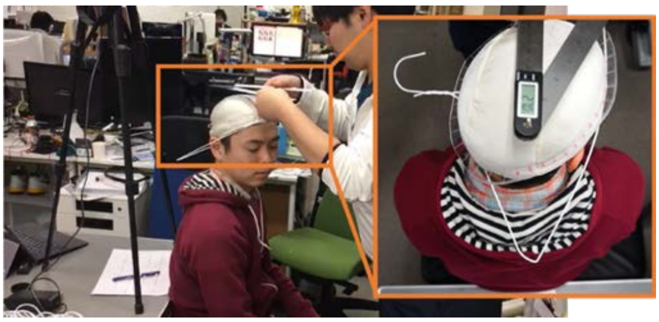


Figure 12. Experimental procedure

4.1 Experimental results

Figure 13 shows the experimental results. The left side of the figure shows the head rotation angle of the subject, and the right side shows the subjective reports given by the subject. As in a previous study [5], left rotation occurred when the hanger contact point was positioned over the left temporal region, and right rotation occurred when contact occurred over the right temporal region.

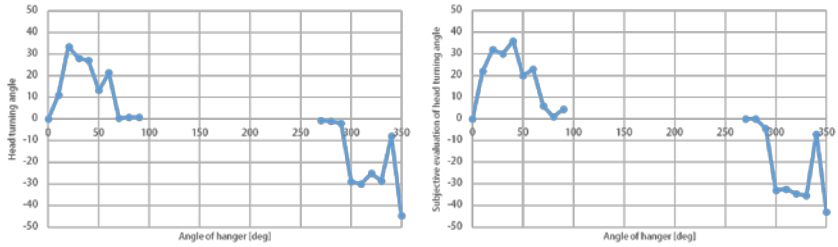


Figure 13. Head turning angle and subjective evaluation at each wearing angle of wire hanger

5 Discussion

In Section 3, we examined the distribution of skin deformation elicited by the hanger reflex using an artificial head with gel as simulated skin. In Section 4, we evaluated the strength of the actual hanger reflex according to the degree of head rotation and subjective reports. Here, we consider the factors influencing hanger reflex-induced skin deformation.

We considered two main candidates as important factors in hanger reflex-induced skin deformation. The first is the peak value of skin deformation (Figure 14), which is thought to be associated with the strength of local skin irritation and also the level of pain induced by the hanger. If the hanger reflex depends on a localized sensation, then this value is an important factor. The second candidate is the integral value of skin deformation (Figure 15). This is the sum of the skin deformation around the entire circumference of the head. If the hanger reflex is caused by distortion of the skin, then this value is an important factor.

Table 1 shows the peak value of skin deformation, integral value, head rotation angle, and subjective evaluation.

Figure 16 and Figure 17 show the results of a correlation analysis between the peak value of skin deformation, the subjective evaluation, and the rotation angle. The vertical axis shows the subjective evaluation or the rotation angle, and the horizontal axis shows the peak value of skin deformation. The figure shows a correlation between these three variables (R = 0.74, 0.68). Figure 18 and Figure 19 show the results of a correlation between the integral value of skin deformation, the subjective evaluation, and the angle of rotation. The vertical axis shows the subjective evaluation or the rotation angle, and the horizontal axis shows the integral value of skin deformation. We found a correlation between the integrated value of skin deformation, the subjective evaluation, and the rotation angle (R = 0.66, 0.6).

The above-mentioned results indicate that peak deformation and the integral value of deformation both may play important roles in the hanger reflex phenomenon. However, the relative importance of these physical properties is not clear. In our experiments, the peak and integral values of skin deformation were highly correlated, likely because the point of contact on the wire hanger is quite small. Therefore, we plan to develop new devices to elicit the hanger reflex, such as an elastic ring, to further examine the contribution of the peak and sum of skin deformation.

In this experiment, we encountered some trials in which the head rotated in the direction opposite to the integral value of the skin deformation. This occurred when the hanger was placed between the 10 ° and 30 ° positions. In this range, the hair on the back of the head of the subject lowered the friction so that the skin of that region did not deform. In our transparent head model, the friction of the simulated skin was uniform and skin deformation was also observed at the back of the head. This circumstance contributed to a deviation between skin deformation measurement, head rotation amount, and subjective evaluation for a specific posture.

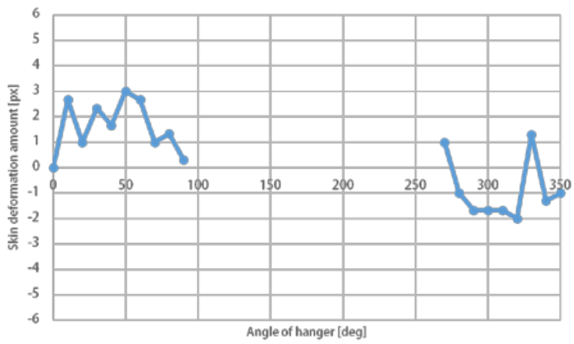


Figure 14. Peak value of skin deformation at each mounting angle of wire hanger

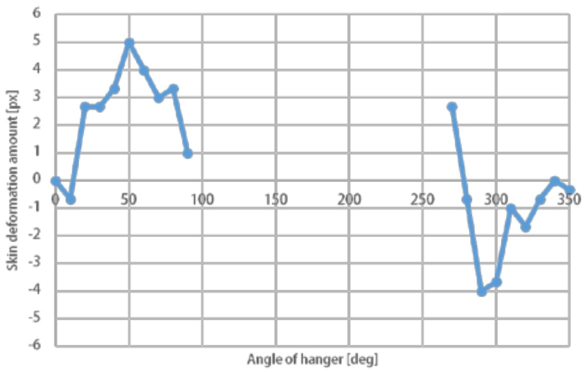
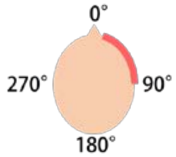
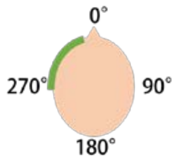


Figure 15. Integrated value of skin deformation at each mounting angle of wire hanger

Table 1. Head turning angle and subjective evaluation for each wire hanger angle





	Angle of hanger [deg]	Peak value of skin deformation [px]	Integral of skin deformation [px]	Head turning angle [deg]	Subjective evaluation of head turning angle
Right temporal region	10	2.67	-0.67	11	22
	20	1	2.67	33.5	32
	30	2.33	2.67	28.15	30
	40	1.67	3.33	27.05	36
	50	3	5	13.25	20
	60	2.67	4	21.4	23
	70	1	3	0.35	6
	80	1.33	3.33	0.8	1
	90	0.3	1	0.8	4.5
Left temporal region	270	1	2.67	-0.6	0
	280	-1	-0.67	-1	0
	290	-1.67	-4	-2	-4.5
	300	-1.67	-3.67	-29.1	-33
	310	-1.67	-1	-30.05	-32.5
	320	-2	-1.67	-25.1	-34.5
	330	1.3	-0.67	-28.65	-35.5
	340	-1.3	0	-7.9	-7
	350	-1	-0.33	-44.75	-43

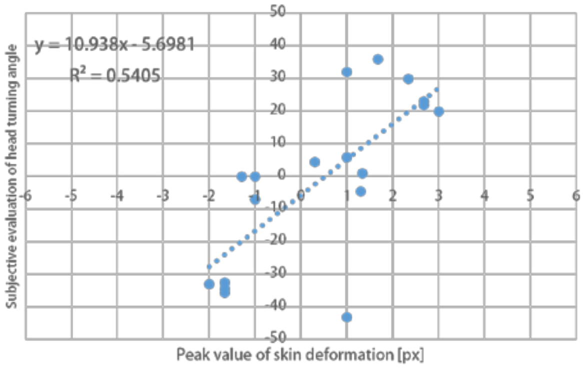


Figure 16. Correlation analysis of the peak value of skin deformation amount and subjective evaluation

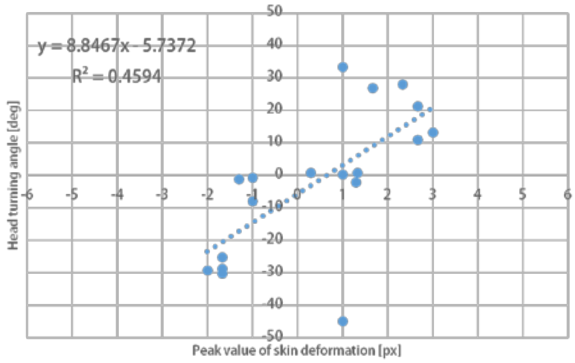


Figure 17. Correlation analysis of the peak value of skin deformation amount and measured head rotation angle

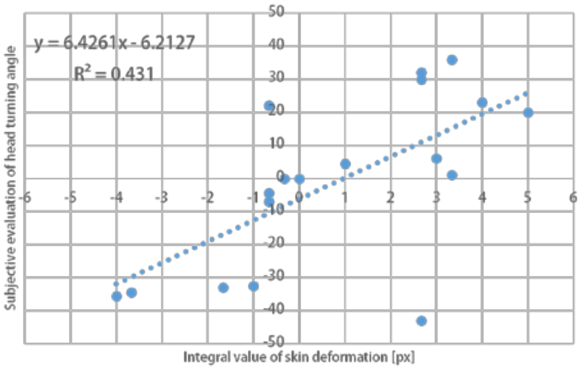


Figure 18. Correlation analysis of the integrated value of skin deformation amount and subjective evaluation

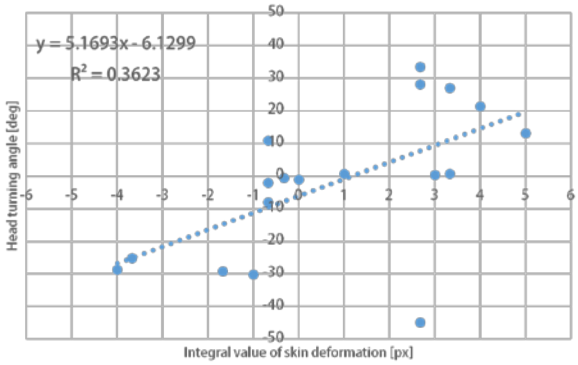


Figure 19. Correlation analysis of the integrated value of skin deformation amount and measured head rotation angle

6 Conclusion

In this study, as a first step towards developing a device that efficiently produces the hanger reflex, we examined the relationship between physical quantitative measurements of skin deformation and the subjective strength of the hanger reflex. To address the challenges associated with measuring actual skin deformation distribution, we created a model using the subject's head shape and measured the hanger-induced deformation of skin-like gel. In our second experiment, we measured the head rotation and subjective strength of the hanger reflex in a human participant.

When comparing skin deformation distribution with the amount of head rotation and subjective strength of the hanger reflex, we found that both the peak value and integral value of skin deformation were highly correlated with the strength of the effect. This made it difficult to determine which variable played a more important role.

We plan to address this issue by comparing the effect of the wire hanger with that of an elastic ring, or by changing the contact shape of the hanger. We also plan to conduct the experiment with multiple participants, and test whether modulating the vertical pressure distribution will impact this phenomenon.

Acknowledgment

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