Development and Evaluation of Vibration and Alternating Temperature Stimuli of a Roller-type Itch-relief Device

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Abstract: Painful thermal stimulation is known to inhibit the itch sensation, which is a significant problem for many diseases. We focused on the thermal grill illusion, which is a well-known phenomenon that can generate pain or a burning sensation without physical damage; we tried to achieve a similar effect via thermal stimulation at a harmless temperature. We have developed a roller-type itch-relief device. When the device is rolled on the user's skin, the skin is alternately exposed to hot and cold stimuli. In addition, vibration is applied so that a virtual scratching feeling is presented without damaging the skin. Results show that the device is effective in terms of relieving the itch sensation, and the effect continued for 8 minutes.

Keywords: Itch, Thermal grill illusion, pain

1. INTRODUCTION

An itch sensation is common to many skin diseases, such as atopic dermatitis and senile xerosis. It can be temporarily relieved by scratching, but this damages the skin and may lead to prolonged illness [1]. It is therefore important to reduce the itch sensation without damaging the skin. In the treatment of atopic dermatitis, itching is commonly suppressed by the administration of a drug (e.g., a steroid or antihistamine). However, drug treatment has the risk of side effects (e.g., adrenal insufficiency, diabetes, and viral skin infection).

Painful thermal stimulation is known to inhibit the itch sensation [2]. This may lead to a type of treatment without the risk of serious side effects; however, the heat causing the pain may burn the skin.

Our idea was to use the itch-relief effect of heat pain at a harmless temperature for treatment of the itch sensation. We focused on the phenomenon called the thermal grill illusion (TGI) [3,4], which is also called synthetic heat [5]. This illusion is a well-known perceptual phenomenon that induces pain or burning sensations without damaging the skin through the simultaneous presentation of hot and cold stimuli to the skin.

We have developed and evaluated roller-type itch-relief devices [6]. The roller is embedded with Peltier devices for temperature stimulation, and a vibrator that presents a virtual scratching feeling. The outer surface of the roller is divided into two parts: one is heated and the other is cooled. Rolling the roller on the skin allows the two parts to alternately touch the skin. We have shown that a certain pain or burning sensation is elicited by the device.

In this paper, after introducing the device setups, we present the results of an evaluation of the itch-relief effect of the device. We investigated the effects of vibration, temperature, and the combination of the two to determine individual and synergetic effects.

2. DEVICE

2.1 Configuration

The system consists of two aluminum parts (outer diameter: 20 mm, length: 50 mm), a potentiometer that measures the rotation angle, a vibrator (Tactile Labs, Haptuator Mark II), two Peltier devices (STS, T150-85-017S), four fans (Sunon, Mighty Mini Fan UF3C3-700), a microcontroller (mbed NXP LPC1768), an audio amplifier (Rasteme Systems, SDA202), acrylonitrile butadiene styrene exterior, and a voltage source (A&D, AD-8723D) (Figure 1, Figure 2). To connect the current source and rotating Peltier devices, we used an audio plug and a leaf spring as a rotary joint.

The roller portion is embedded with two Peltier devices, which are stacked to achieve efficient heating and cooling (Figure 3, Figure 4). One side of the stack is in contact with and heats one side of the cylinder, while the other side of the pile is in contact with and cools the other side of the cylinder.
Normally, the TGI is elicited by hot and cold stimuli presented simultaneously and close to each other. However, this simultaneous stimulation requires a large setup and consumes much energy. In contrast, we presented hot and cold stimuli using a single cylinder, which allows for a compact and energy-efficient design because a single Peltier device works as both a hot thermal source and a cold thermal source. We expected the TGI to be generated through the presentation of hot and cold stimuli to the skin alternately through the rotation of the roller (Figure 5).

Although our first prototype could initially present hot and cold stimuli separately, it gradually became hotter owing to the heat generated by the Peltier device [6]. To overcome this problem, we embedded an array of micro-fans to release heat. The roller was also redesigned to efficiently transmit heat from the Peltier device to the aluminum parts.

A vibrator is embedded in the grip of the proposed device to produce a virtual scratching sensation. The vibration is a rectangular wave with a frequency of 50 Hz that produces a sensation similar to scratching. The waveform and frequency were chosen from the results of preliminary experiments [6]. The amplitude is set proportional to the speed of rotation, which is obtained from the potentiometer attached to the roller.

2.2 Stability of temperature
To ensure safety, the temperature of the roller surface must be within a range that does not damage the skin, which is less than approximately 44°C [7, 8]. We adjusted the current applied to the Peltier device to keep the roller surface below 44°C. Figure 6 shows the surface temperatures of the two sides of the roller when constant current of 0.8 A was applied to the Peltier devices. The room temperature was 23°C. The measurement was carried out for 30 minutes, and the high-side temperature was maintained below 43°C, while the low-side temperature was below 15°C (Figure 6).
2.3 Generation of pain sensation

We evaluated the sensation elicited by hot and cold temperature stimulation. We compared three temperature conditions of the roller and evaluated the performance via a questionnaire.

Eight healthy naive participants (five males and three females) between 21 and 63 years of age participated in the study. None had atopic eczema or chronic skin disease. They did not have any prior knowledge of TGI or other related illusions. This evaluation was conducted in a room with temperature of around 20°C.

Three temperature conditions, “cold only”, “hot only” and “alternate temperature” were prepared. The alternate-temperature condition is what we mentioned in the previous section, with a temperature of 40°C for the hot side and 15°C for the cold side. In the case of the cold-only condition, the temperature was set to 5°C on both sides of the roller by putting the roller in a refrigerator in advance. In the case of the hot-only condition, the temperature was set to 45°C on both sides of the roller by putting the roller in a warmer in advance.

Participants were asked to voluntary roll the device on the inner side of their right forearm for 10 seconds per trial. For each trial, they were asked to choose words that described the sensation they felt from the following: cool, cold, warm, hot, stinging, itching, tickling, wet, painful, good feeling, strange feeling. Some of these words (cool, cold, warm, hot, tickling, stinging, painful) were taken from previous works on nocuous temperature sensation [3, 9]. Other words (itching, wet, good feeling, strange feeling) were responses given by other participants in our preliminary experiments. The procedures were repeated 15 times per one participant, five times for each temperature condition. The order of the trials was randomized.

Figure 7 shows the result of the questionnaire. The horizontal axis shows the sensation quality, and the vertical axis shows the answer rate.

Under the cold-only condition, “cold” was naturally selected most, followed by “cool”. “Wet” was also selected, possibly because the cold temperature recalled the thought of condensation. Under the hot-only condition, “warm” was selected most, followed by “hot”. Meanwhile, under the alternate-temperature condition, “cool”, “cold” “warm” and “hot” were all selected, naturally because hot and cold stimuli were alternatively presented.

What made the alternate-temperature condition different from the other conditions were the descriptions “painful” and “strange feeling”, the rates of which were 22.5% and 32.5%, respectively. These are typical expressions for the known TGI, and we may thus say that the device can partly deliver the TGI; the rates were similar to those observed in previous work [3].

After the experiment, six of the eight participants commented that hot and cold sensations were perceived simultaneously (not alternately) under the alternate-temperature condition.

3. EVALUATION

We evaluated the manufactured device under real itch conditions. This experiment was approved by the ethics committee of the Shiseido Research Center.

3.1 Conditions

Nine healthy male participants aged between 28 and 51 years participated in the study. None had atopic eczema or chronic skin disease. This experiment was conducted in temperature and humidity testing room which was maintained at 22°C and 45%RH.

We prepared the four test conditions listed in Table 1. Under condition O (Off), neither the vibration stimulus nor alternating temperature stimulus was presented. Under condition T (Temperature), only the temperature stimulus was presented. Under condition V (Vibration), only the
vibration stimulus was presented. Under condition VT, both the vibration and temperature stimuli were presented. When the temperature stimulus was not presented (i.e., under conditions O and V), the temperature of the roller was set to body temperature (33°C) beforehand. To compare with the test conditions, we prepared a control condition in which we did not apply the roller.

### 3.2 Procedure

All participants participated in the four experiments having the four different test conditions on different days. The order of presentation of the four test conditions was randomized.

One trial involved testing for one of the four test conditions and one control condition. The procedure for one trial was as follows. Participants washed and dried their cheeks. They then placed a cotton pad containing 7 mL of 2.5% lactic acid solution onto their cheeks to elicit an itch sensation [10]. The liquid is known to elicit an itch sensation. After 8 min, the cotton pad was removed. After another 1 min, the participants rolled the device on their cheek for 15 s. (Under the control condition, participants waited for 15 s without using the device.) Participants were asked to rate the intensity of the itch sensation for 8 min. The procedure was then repeated for the other cheek under the other condition (the test condition if the first trial was for the control condition, and vice versa). The order of conditions (test condition or control condition) and the order of cheeks (left or right) were randomized.

The participants were asked to rate the itch sensation using a visual analogue scale (VAS) immediately before the removal of the cotton pad, immediately after the removal of the cotton pad, 1 min after using the device, and every minute for 8 min after using the device. The left end of the VAS corresponds to “no itch,” and the right end corresponds to “an itch that was irresistible to scratch.”

After the completion of experiments for all four test conditions, we asked the participants to answer a questionnaire to determine the subjective effect for each condition. The content of the questionnaire was “how effective was the device?”, for which there were four possible answers: very effective, effective, slightly effective, and ineffective.

Four participants stopped the experiment owing to roughening of the skin due to lactic acid application. They were excluded from the analysis.

### 3.3 Results

Figure 8 and Table 2 shows the temporal change in averaged value of the itch sensation. Condition C indicates the value of the control condition. Figure 9 shows the result of the questionnaire. The average VAS rating for

![Figure 8: Averaged intensity of itch sensation under five conditions](image)

### Table 1: Experimental conditions

| Temperature | Vibration |
|-------------|-----------|
| Condition O | –         | –         |
| Condition V | –         | ✔         |
| Condition T | ✔         | –         |
| Condition VT| ✔         | ✔         |

![Table 2: Averaged values and standard deviations of VAS scale at each time points](image)

| Mean | C | O | T | V | VT |
|------|---|---|---|---|----|
| before removing pad | 87.7 | 88.4 | 80.6 | 79.6 | 85.6 |
| after removing pad | 76.85 | 76.2 | 73.6 | 65 | 73.7 |
| after removing 1min | 84.6 | 88.6 | 78.6 | 77.8 | 79.4 |
| using device | 84.35 | 49.8 | 19.8 | 31.4 | 32.4 |
| after using 1min | 81.55 | 62.8 | 25.6 | 34.2 | 39.4 |
| 2min | 79 | 63 | 22.8 | 34.4 | 35.6 |
| 3min | 75.7 | 62.4 | 23.6 | 32 | 33.2 |
| 4min | 75.85 | 65.4 | 23 | 31.2 | 35.2 |
| 5min | 72.2 | 61 | 25.4 | 27.2 | 31.8 |
| 6min | 68.8 | 59.4 | 23.6 | 27 | 30.2 |
| 7min | 64.15 | 56.6 | 22.6 | 27.8 | 29.4 |
| 8min | 58.25 | 57.6 | 21.2 | 28 | 25.4 |

| SD | C | O | T | V | VT |
|----|---|---|---|---|----|
| before removing pad | 6.969577 | 6.024948 | 9.343447 | 13.2778 | 10.35857 |
| after removing pad | 12.02419 | 11.56287 | 9.659193 | 13.6565 | 12.38951 |
| after removing 1min | 7.891055 | 6.69328 | 6.387488 | 16.54388 | 15.46932 |
| using device | 9.555103 | 22.07261 | 12.65701 | 13.99286 | 17.70028 |
| after using 1min | 13.11535 | 15.57883 | 19.21718 | 19.6901 | 6.426508 |
| 2min | 12.73774 | 22.3935 | 12.96919 | 20.74367 | 17.28583 |
| 3min | 13.28698 | 21.8472 | 15.25778 | 19.58316 | 18.06101 |
| 4min | 10.39621 | 21.00714 | 15.45962 | 20.82547 | 19.17551 |
| 5min | 10.58507 | 20.22375 | 17.75669 | 24.09772 | 20.06739 |
| 6min | 12.45793 | 24.44995 | 18.95521 | 26.04803 | 18.75367 |
| 7min | 13.8485 | 22.57875 | 18.60914 | 31.18814 | 18.98157 |
| 8min | 16.3812 | 29.08264 | 20.42547 | 33.88953 | 19.15202 |
condition O dropped only immediately after applying the roller. Therefore, condition O (using the device without a vibration stimulus or temperature stimulus) has only a temporary effect. The questionnaire result was also the worst for condition O.

The average VAS rating for condition T was the lowest among the five conditions. Therefore, condition T (using only the alternating temperature stimulus) is the most effective. The results of the questionnaire for condition T were also good.

The average VAS rating for condition V was much lower than that for condition O. The result of the questionnaire showed slight subjective effectiveness compared with condition O.

The average VAS rating for condition VT was almost equal to that for condition V, but the variance was smaller. Although the VAS rate for condition VT was lower than that for condition T, the questionnaire result for condition VT was the best among conditions, suggesting that vibration may contribute to subjective effectiveness.

4. CONCLUSION

To relieve the itch sensation, which is an important problem for many skin diseases, we proposed the simultaneous use of alternating hot and cold temperature stimulation and vibration. The former was expected to generate a painful sensation that is known to relieve the itch sensation, and the latter was expected to convey to the user a feeling of scratching.

We developed a roller-type handheld device for itch relief. It was composed of Peltier devices, a potentiometer, air fans, and a vibrator. We designed the device to be portable as itching can occur at any time.

The ability of the device to reduce the itch sensation was evaluated. We verified the individual effects of alternating the temperature stimulation and vibration stimulation. The results show that alternating the temperature stimulation is effective in terms of relieving the itch sensation, and the effect continued for at least 8 minutes after using the device. The effectiveness of vibration stimulation was approximately same value, and the result of a questionnaire suggested that vibration may contribute to subjective effectiveness. There was no synergistic effect between subjective effectiveness. We will continue the development and evaluation of the proposed device. The hardware should be optimized by modifying the diameter of the roller, which affects the interval of hot and cold stimuli and is important for conveying the TGI, and by optimizing the vibration waveform to present a more effective scratching feeling.

In this paper, we focused on painful thermal stimulation. However, it is known that painless cold stimulation also relieves the itch sensation. We will therefore compare our method with the condition of using only a cold stimulus. We will then apply the device to participants with skin diseases, such as atopic diseases and dry skin.

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