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# 360-Degree Cold Sensation Presentation via Encircling Airflow Based on the Coandă Effect

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***Abstract*—This study proposes a method to represent a 360-degree cold sensation by optimizing the use of jet nozzles, considering the curved geometry of the human body. The method leverages the Coandă effect, a phenomenon where jets adhere to curved surfaces, to achieve wide-area cold perception with a reduced number of jet nozzles. To determine the nozzle conditions required to exceed the threshold of 360-degree cold perception throughout the neck, the target body part of this study, temperature changes were measured using a silicone phantom. Experimental results indicate that a single nozzle was insufficient to exceed the threshold, whereas two nozzles with an inter-nozzle angle of 90 degree or greater successfully exceeded the required temperature change for cold perception. A user study was conducted to evaluate participants' perceived cold sensation across the neck. The results confirmed that the proposed method can provide 360-degree cold sensation. They also demonstrated statistically significant differences in the effective angle ranges for 360-degree cold sensation between different nozzle-tip directions; parallel (83.0 to 118.4 degree) and center (124.7 to 139.4 degree) nozzle-tip configurations. These findings offer valuable insights that could contribute to the advancement of future thermal displays.**

***Index Terms*—cold sensation, non-contact thermal display, 360-degree, Coandă effect.**

## I. Introduction

In virtual reality, environmental reproduction is essential for delivering immersive experiences. Effective simulation of sensory cues, including temperature, enhances user presence and realism. However, efficiently reproducing cold sensations remains challenging. In real-world settings, humans perceive temperature variations as an enveloping sensation, as if surrounded by cold air. Replicating this effect typically requires multiple devices to create a large-area cooling effect, often resulting in bulky hardware. Contact-based thermal feedback offers a more compact alternative but may cause discomfort. Therefore, a key challenge is developing a method to evoke widespread cold sensations without direct contact or large-scale hardware.

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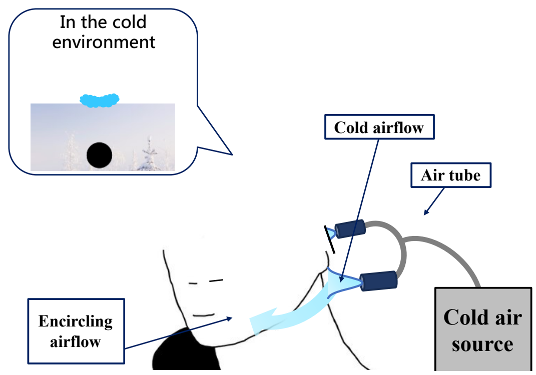



Fig. 1. 360-degree cold sensation presentation via encircling airflow based on the Coandă Effect.

Conventional non-contact environmental reproduction systems generate cold sensations by altering the ambient air temperature surrounding the user [5], [6]. However, these methods often exhibit slow response times, limiting their ability to deliver instantaneous cold sensations. An alternative approach utilizes multiple fans to provide localized cooling through airflow, but this requires substantial space.

On the other hand, jet-based airflow methods offer a promising alternative, enabling rapid local skin temperature modulation while reducing hardware size and overcoming the limitations of traditional techniques. These methods allow for spatially distributed cooling across large skin areas without the discomfort of direct mechanical contact, though they may introduce wind pressure effects. Enhancing the effectiveness of cold sensation presentation requires considering the morphological and psychophysical characteristics of the human body, including its curved surfaces and the relationship between physical stimuli and perceptual responses. Strategic utilization of jet airflow can optimize cold sensation distribution and enhance the user experience.

The Coandă effect plays a crucial role in achieving efficient cold sensation presentation with a minimal number of nozzles in jet-based approaches. This phenomenon occurs when airflow, due to its viscosity, entrains ambient air and generates a low-pressure region, causing it to adhere to a curved surface [7], [8]. This property allows for airflow to be directed along curved surfaces, effectively extending the cooling sensation beyond the immediate contact point of the jet. As a result, a broader cooling perception can be induced, even with a reduced number of nozzles. Despite its potential, the impact of the Coandă effect on human cold perception remains largely unexplored.

This study aims to develop a 360-degree cold sensation presentation system that utilizes encircling airflow with a minimal number of nozzles, leveraging the Coandă effect. As illustrated in Fig. 1, we focus on the neck as the primary target region for cold stimulation, as it is typically less covered by clothing and more directly exposed to external temperature changes than other body regions, making it an ideal site for thermal stimulation.

The key contributions of this study are as follows:

- We proposed a 360-degree cold sensation presentation method that employs encircling airflow based on the Coandă effect, using a reduced number of nozzles.
- We analyzed the temperature distribution caused by the surrounding cold airflow and explored its impact on human thermal perception.
- We investigated the spatial arrangement and jet angles of the nozzles to enhance cold sensation distribution and identified the effective angular range for inducing a perceivable cold sensation.

## II. Related Works

There are two main approaches to providing cold stimuli: contact and non-contact methods. Contact methods include the use of Peltier devices [1] and tubes filled with cold fluids that are placed in direct contact with the skin [2]. These methods offer precise temperature control and stable cooling performance; however, they are less responsive to rapid temperature changes and may cause discomfort due to prolonged skin contact.On the other hand, non-contact methods include approaches using Mist Vaporization and airflow. Mist Vaporization [3], [4] offers excellent immediate response performance but is limited to cooling localized areas. As an example of methods using airflow, blowing air from multiple directions into the head of a user wearing a head mounted display to improve the sense of presence [5]. The use of numerous blower fans and nozzles results in a large display system. Other studies have explored devices equipped with fans, blowers, mist generators, and infrared lamps installed above the user's head to reproduce surrounding aerial conditions to present thermal sensations [6]. These devices alter the air around the user for a cold sensation. However, it is difficult to change the thermal sensation instantly.

There is research that focuses on how humans perceive cold sensations, aiming to present a spatially continuous cold sensation using fewer elements [9]. This study investigated the optimal distance between the cold stimuli presented by two distant nozzles to allow users to perceive continuous cold sensations, not discrete cold sensations. However, it was assumed that the skin surface for stimulus presentation is flat, not rounded, so it has the limitation of presenting a cold sensation using an airflow for the rounded body parts. On the other hand, there is a study focusing on airflow and thresholds [10]. Lee et al. aimed to explore the potential of using airflow as a non-contact wearable tactile display that requires firm contact on the skin. They reported a valuable psychophysical knowledge investigating the intensity, duration, and distance thresholds of airflow perception on various body locations. However, there are some different points from our study. First, their study focused on tactile representation, not cold representation. As a result, we examine the temperature change using a cold airflow. Second, we focus on the coandă effect to minimize the number of nozzles to encircle the human body. Ranasinghe et al. reported the work "ambiotherm", which use a heat source and wind stimuli [11]. They mainly focused on low-latency and multi-sensory stimulation using contact-type heat source and wind stimuli, while our study focuses more on non-contact stimulation and utilizing the Coandă effect to reduce the number of nozzles. Furthermore, there is a study on a thermal sensation presentation utilizing the Coandă effect [12]. However, this study does not address the relationship between perception and temperature changes caused by the airflow wrapping around the skin surface due to the Coandă effect.

## III. Method

In this section, we describe a method for presenting a 360-degree cold sensation via an encircling airflow with fewer nozzles and the physical effects to affect the cold sensation. In this study, we focus on the neck as a rounded body part for cold sensation presentation because it is not covered by clothing and can be easily cooled all around. We first conduct a temperature measurement experiment to objectively and consistently examine the physical changes using a phantom. This experiment aims to investigate the possibility that the Coandă effect can change the temperature more than a threshold across 360°. The results would provide a suggestion for the design of the device configuration. This experiment will be followed by a user study to explore whether the proposed device can induce a cold sensation as intended.

### *A. Enveloping Cold Stimulus Presentation Using the Coandă Effect*

The 360-degree cold sensation presentation device proposed in this research uses cold airflow generated by the vortex effect, which can instantly generate cold airflow. The vortex effect is a phenomenon in which compressed air creates a vortex flow and the centrifugal force causes the outside to get hotter and the inside to get colder. The cold air inside expands and flows to the cold air outlet, thereby extracting a cold air flow [13]. It has been confirmed that the cold air flow generated by the vortex effect allowed the presentation of a cold sensation [14], [15]. The cold air flow produced by this

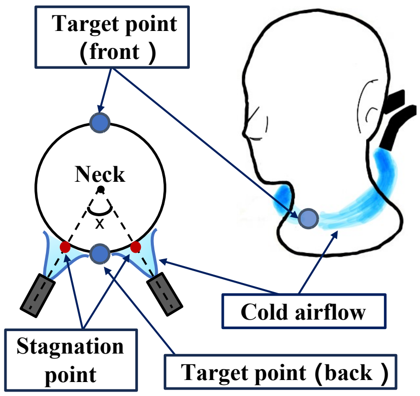



Fig. 2. A target point intended for cold perception through airflow adherence to a surface caused by the Coandă effect.

effect is presented to the skin through a nozzle to investigate which point on the skin surface is perceived cold.

As shown in Fig. 2, the target point (front), which is the target position for cooling, is located at 12 o'clock on the clock when the neck is viewed from above, while the target point (back), which is the other target position for cooling, is located at 6 o'clock on the clock. The airflow does not reach from the nozzle in a straight line but may go around and reach the target points. When cold air is perceived at the target points, it is assumed that a user perceives cold entirely from the directly hit point to the target points. By investigating the minimum angle (x in Fig. 2) at which the nozzles are placed and a user perceives cold, efficient presentation is achieved. $X_{\mathrm{f}}$ and $X_{\mathrm{b}}$ are defined as the angles at which the nozzles are placed and a user perceives cold at the front and back target points, respectively. The minimum number of nozzles required to present cold sensation throughout the neck is determined by the relationship between $X_{\mathrm{f}}$ and $X_{\mathrm{b}}$.

### *B. Physical Effects Influencing Perception*

We assume that convective heat transfer due to airflow is a major factor in perception of environmental cold. We investigate whether the Coandă effect can occur on the surface of the neck by measuring the temperature change using a phantom. Based on a previous study [16], the threshold for cold perception was set at 0.3 °C, and if the temperature change at the target point was greater than the threshold, the Coandă effect is effective to present cold perception.

From this investigation, we assume that the Coandă effect affects a cold spatial presentation when the thresholds are exceeded.

## IV. Experiment 1 - Measurement of Temperature Change

The temperature change of the skin surface due to convective heat transfer is investigated. The experiment is efficiently conducted by using a phantom of the neck instead of the human neck as the measurement object.

TABLE I
Material Properties [18], [19]

| Substance | Density | Specific heat capacity |
|---|---|---|
| Skin | 1200 $\mathrm{kg/m^3}$ | 3600 $\mathrm{kJ/kg \cdot {}^\circ C}$ |
| Silicone | 970 $\mathrm{kg/m^3}$ | 1600 $\mathrm{kJ/kg \cdot {}^\circ C}$ |

### *A. Experimental Environment and Conditions*

Fig. 3 shows the neck phantom and the experimental environment. A copper plate (2.0 $\mathrm{mm}$ thick) is formed into a cylindrical shape with a diameter of 120 $\mathrm{mm}$ [17] and filled with water. The water is heated by a water heater (SUNART IC control heater SCH-900) to bring the surface of a silicon sheet (1.0 $\mathrm{mm}$ thick) covering the copper plate to the temperature of human skin (33 to 34 °C). The temperature change of the silicon sheet is measured with a thermal camera (Avionics InfReC R450, sensitivity 0.025 °C at 30 °C). Each nozzle (cross-sectional area 8 $\mathrm{mm}$) was connected to a vortex tube (Tohin AC-50), which can generate a cold air flow using compressed air, and the cold air was blown out. The airflow of cold air at the outlet was 1.5 $\mathrm{m/s}$ and this airflow temperature was 0 °C [15]. The airflow velocity at the nozzle tip was measured using digital anemometer (HoldPear HP-856A). The laboratory temperature was set to 25 °C by an air conditioner.

In this experiment, temperature changes were measured using a single nozzle or two nozzles. The single nozzle was placed above the target point (neck). The two nozzles were placed with angles adjusted at intervals of 30 ° from 0 ° to 150 °. The measurements were performed five times for each condition, and the results are presented as the average of these measurements.

Since the subject of this experiment is a silicone sheet rather than skin, it is necessary to adjust the target threshold. The temperature change in the silicone phantom is calculated from the change in skin temperature, as follows:

$$\Delta T_{\mathrm{p}} = \frac{c_{\mathrm{s}}\rho_{\mathrm{s}}V_{\mathrm{s}}}{c_{\mathrm{p}}\rho_{\mathrm{p}}V_{\mathrm{p}}}\Delta T_{\mathrm{s}}, \tag{1}$$

where $\Delta T_{\mathrm{p}}, \Delta T_{\mathrm{s}}$ are the temperature changes of the silicone phantom and skin temperature, respectively. $c$, $\rho$, $V$ are the specific heat capacity, density, and volume, respectively, and the subscript "p" and "s" denote phantom and skin, respectively. As cold receptors are located directly under the epidermis at a depth of 0.15 to 0.17 mm [20], we assumed the thickness of the skin tissue to be 0.2 mm, while the thickness of the silicone phantom was 1.0 mm. Then, the volume proportion is calculated as $V_{\mathrm{s}}/V_{\mathrm{p}} = 0.2/1.0 = 0.2$, assuming the same area is cooled. The characteristics of the silicone sheet and skin are listed in Table I. Therefore, we adjusted the threshold of temperature change for skin, 0.3 °C [16], to 0.17 °C, which is the threshold for silicone sheet in the experiment with (1).

The parameters used in Experiment 1 are listed in Table II.

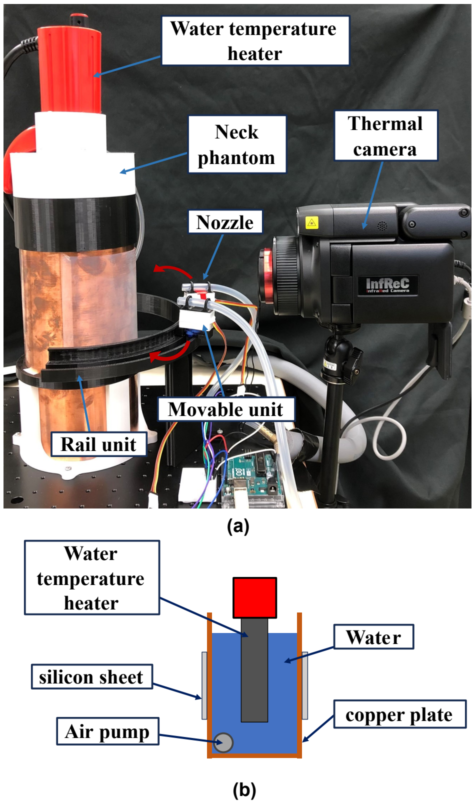



Fig. 3. Temperature measurement experiment environment: (a) Overview, (b) Neck phantom structural diagram.

TABLE II
PARAMETERS IN EXPERIMENT 1

| | |
|---|---|
| Distance of phantom surface to nozzle | 50 mm |
| Room temperature | 25 °C |
| Nozzle angle | 0 to 150 ° (interval of 30 ° ) |

### B. Result

Fig. 4 shows the measured temperature when cold airflow was applied to the phantom with a 90 ° inter-nozzle angle between two nozzles. Fig. 5 shows the measured temperature change distribution on the surface of the neck phantom. Fig. 5(a) shows the target point and the distribution of temperature change for each angular condition, while Fig. 5(b) graphs the temperature change close the target point (front). The red circle in Fig. 5(a) and the red line in Fig. 5(b) show the above mentioned threshold, which is 0.17 °C. In Fig. 5(a), dotted lines indicate the three conditions that do not exceed the threshold at the target point (front) , while solid lines indicate three conditions that do exceed the threshold.

In terms of the target point (back), all conditions exceeded the threshold. In terms of the target point (front), the conditions of the two nozzles with inter-nozzle angles of 90 ° or more exceeded the threshold so that those conditions would induce cold perception of the entire neck. However, the conditions of a single nozzle and the two nozzles with inter-nozzle angles of 60 ° or less would not.

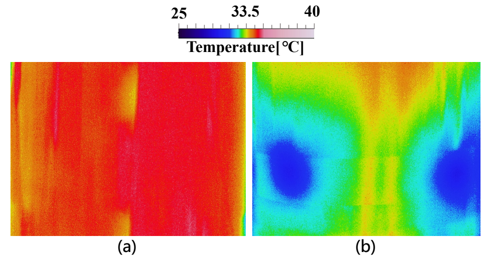



Fig. 4. Measured temperature (angle 90): (a) Front view, (b) Back view

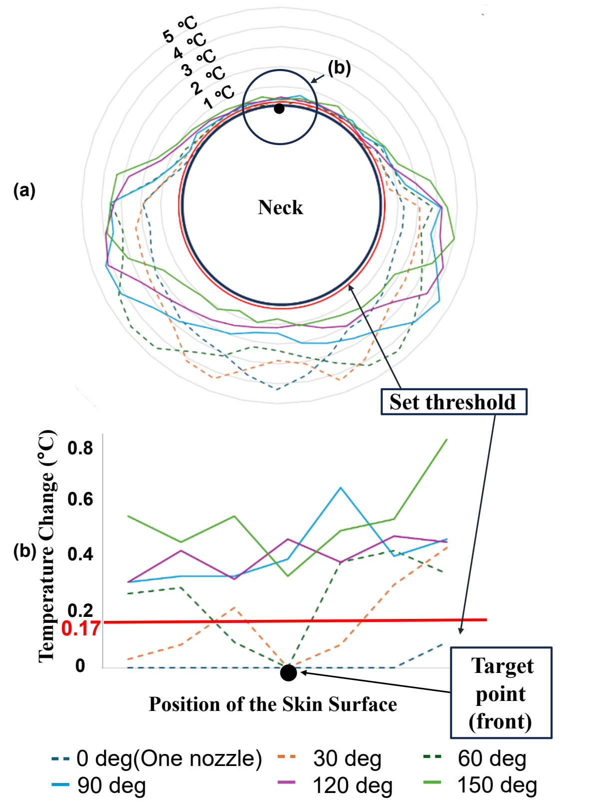



Fig. 5. Measured temperature change: (a) Temperature change distribution, (b) Temperature change near the target point (front).

## V. EXPERIMENT 2 - USER STUDY

Due to the Coandă effect, airflow encircles a rounded surface. In Experiment 2, we verify whether the proposed method can elicit cold sensation both at front and back target points with different angles between nozzles. Based on the results of Experiment 1, it is considered that only one nozzle, or an angle of 60° or less between two nozzles, could not provide a 360° cold sensation. In Experiment 2, two nozzles were used and the minimum angle between these nozzles was set at 40°, which is smaller than 60° with a margin of error to account for individual differences in perception. In temperature change measurements, the airflow was presented with the nozzle tip directed toward the center of the neck. However, in this experiment, to investigate the influence of the Coandă effect based on the nozzle tip orientation, a condition with the nozzle tip parallel to the surface is added. By aligning the nozzle tip parallel, the Coandă effect is expected to allow the airflow to wrap further around to the front of the neck, making the effect more effectively utilized.

### *A. Cold Stimulus Presentation Device*

The developed experimental device and the range of motion of the nozzles and the airflow center point are shown in Fig. 6.

In order to investigate changes in perception depending on the direction of the airflow, two types of device were developed. A device with the nozzle tip positioned in the center of the neck as shown in Fig. 6(a-c) ( "nozzle-tip-center device") and a device with the nozzle tip positioned parallel to the neck as shown in Fig. 6(d-g) ( "nozzle-tip-parallel device"). The distance between the airflows can be adjusted by moving two nozzles with servo motors.

The part connecting the servo motor (Tower Pro Pte Ltd SG90-HV) and the nozzles, as well as the rail section, were created using a 3D printer (Raise3D Pro2 with PLA filament). The nozzles are connected to a vortex tube, which blows cold air against the neck. A proportional solenoid valve (Positive-flow-202 from Asco) is used to control the airflow. The motion in the nozzle-tip-center device (Fig. 6(a-c)) and the linear motion in the nozzle-tip-parallel device (Fig. 6(d-g)) are both based on a pinion-rack mechanism. In the nozzle-tip-center device, the angle is adjusted from 40 $^\circ$ to 160$^\circ$ in 20$^\circ$ increments. In the nozzle-tip-parallel device, where the nozzles are moved to cool the same positions of the neck as in the nozzle-tip-center conditions, although the airflow directions are different.

### *B. Experimental Conditions*

Fifteen experimental participants (15 males, 22-28 years of age) participated in all experiments. The participants were not involved in the development of the system. They were paid approximately 10 USD in Amazon gift cards for participating in the experiment. The recruitment of participants and the content of the experiments were approved by the Institutional Ethics Committee of the Institute of Systems and Information Engineering, University of Tsukuba, Japan (approval number 2024R872) , and the participants agreed to participate in the experiments with written informed consent.

Fig. 7 shows the experimental environment. The participants wore a noise-canceling headphone, and white noise was played to block the influence of auditory information. In order to eliminate postural deviation, the participants were instructed in advance that they should always fix their head in the head position fixation. The room temperature was set to 25 °C during the experiment.

The participants were asked to push a key button using a keyboard according to the instructions. After the airflow is presented for five seconds, the experiment transitions to the response phase. The participants are asked to answer whether they perceived cold, responding with either "Yes" or "No." After the response, the participant used an electric heating muffler (The KODEN USB MUFFLER) to initialize the skin temperature. Then, the experiment goes to the next trial until the end of the experiment.

TABLE III
PARAMETERS IN EXPERIMENT 2

| | |
|---|---|
| Distance of neck surface to nozzle | 50 mm |
| Room temperature | 25 °C |
| Nozzle angle | 40 to 160$^\circ$ (interval of 20$^\circ$ ) |

We use the method of limits. An ascending series of widening the angle between the nozzles and a descending series of closing the nozzles were measured twice each. A threshold was calculated from the average of the ascending and descending results obtained for each airflow velocity. Finally, we investigated the relationship between the nozzle angle, airflow, and nozzle orientation required to perceive cold at the target point (front).

The airflow velocity has three levels in the experiment. Regarding the airflow used, the airflow velocity "large" was set to 2.5 $\mathrm{m/s}$, which is the maximum airflow velocity of the compressed air machine used in the experiment. The smallest airflow velocity was set to 1.5 $\mathrm{m/s}$. Because airflow below this level resulted in few conditions of the nozzle distances exceeding the threshold, which is 0.17 °C, at the target point (front) based on Experiment 1. The medium airflow velocity was set to 2.0 $\mathrm{m/s}$, which is the middle of the maximum and minimum rates.

The distance from the nozzle tip to the skin surface was set to 50 mm based on the length of the core region, where the distribution of velocity and density is relatively uniform. The same conditions were used in case of the back of the neck.

The parameters used in Experiment 2 are listed in Table III.

### *C. Result*

The two-way analysis of variance (ANOVA) was performed for the resultant thresholds of cold perception at the significance level of 0.05. The statistics for the nozzle tip angle factor for the front and back of the neck were F(1,174)=179.772 and F(1, 174)=45.325, respectively. They showed a statistically significant effect between different nozzle-tip directions for both the front and back of the neck. However, no statistically significant effects were found for airflow velocity, where the statistics were F(2, 174) = 0.395 and F(2, 174) = 1.029 for the front and back of the neck, respectively. The results of multiple comparisons of the factor of nozzle tip direction showed significant differences between the parallel and center conditions. The samples of the airflow velocity factor are summed up in each nozzle-tip direction because no significant difference was found as for the airflow velocity.

Fig. 8(a) and (b) show the thresholds for cold perception at the front and back of the neck, respectively. The mean thresholds of the parallel and center nozzle-tip directions were $83.0 \pm 21.0$ and $124.7 \pm 20.6$ , respectively, in the case of the

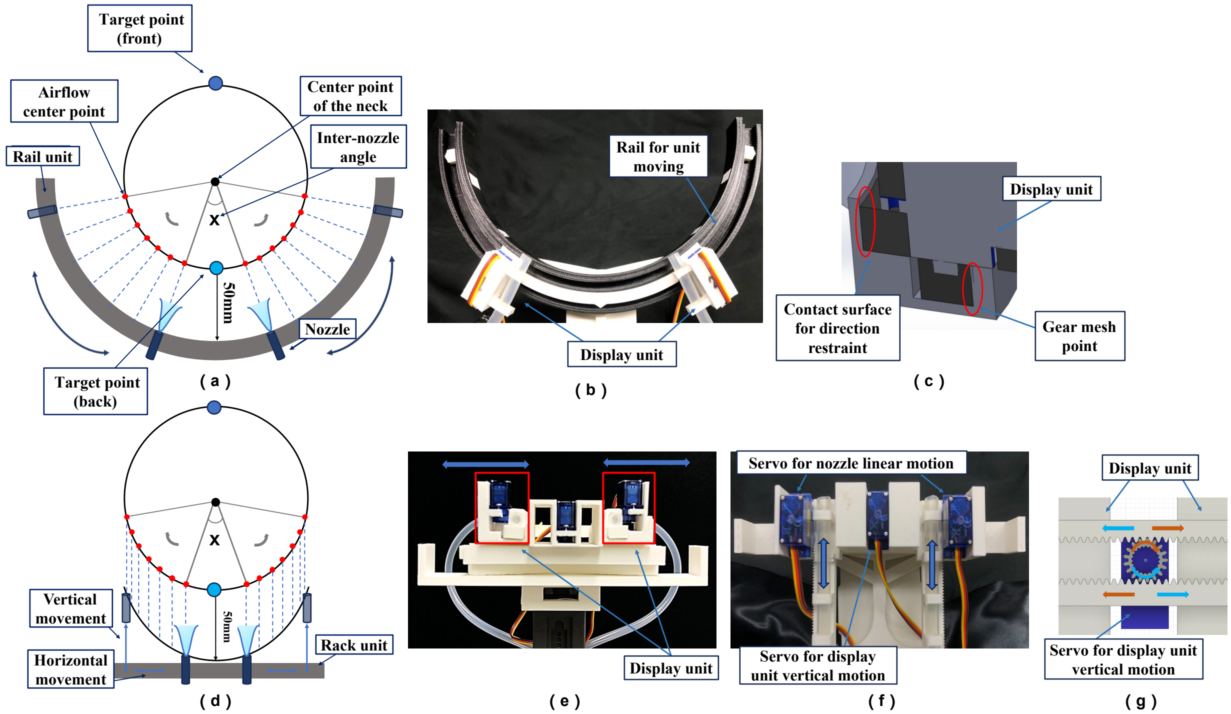



Fig. 6. Nozzle movement and device configurations: (a-c) Nozzle-tip-center device: movement and airflow center position (a), device (b), CAD drawing (c). (d-g) Nozzle-tip-parallel device: movement and airflow center position (d), front and top views of device (e,f), CAD drawing (g).

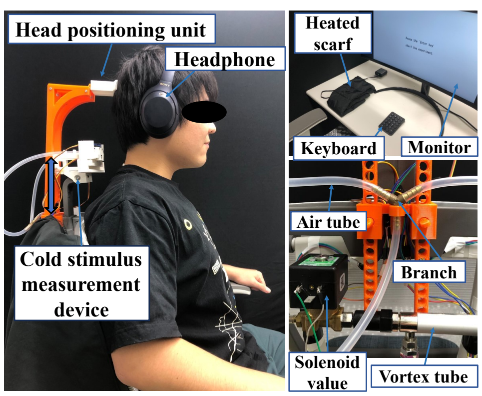
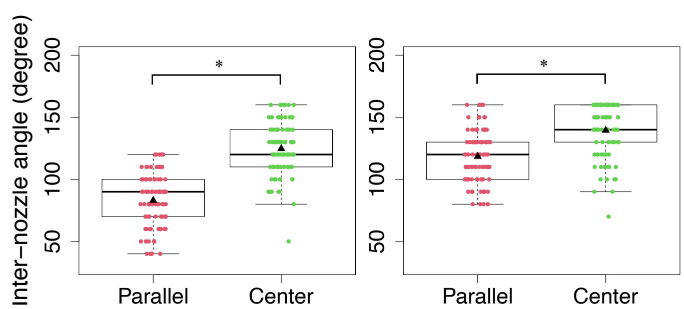



Fig. 7. Environment for experiment.




(a) Front (b) Back

Fig. 8. Thresholds for cold perception in nozzle-tip-parallel and nozzle-tip-center types: (a) front of the neck, (b) back of the neck. The points show all the thresholds, and the triangles indicate the means. Outliers, which fall beyond 1.5 times the interquartile range below the first quartile or above the third quartile, were excluded in the box plot. $*p < 0.05$

front of the neck, while the counterparts in the case of the back of the neck were $118.4 \pm 20.2$ and $139.4 \pm 21.5$ , respectively.

## VI. Discussion and Limitation

According to the results of the temperature measurement in Experiment 1, when the angle between the nozzles was 90 ° or greater, a temperature change exceeded the threshold [16] at both the front and back of the neck. It indicates that part of the airflow reached the entire neck while the other part of the airflow detached. In addition, it would be inappropriate to design a device with a single nozzle for a 360-degree cold sensation display.

According to the results of the user study in Experiment 2, the graph in Fig. 8(a) showed that the center condition requires a greater angle between the nozzles to cool the front of the neck than the parallel condition. In contrast, as shown in Fig. 8(b), the parallel condition requires a smaller angle between the nozzles to cool the back of the neck than the center condition. In summary, the results confirmed that the proposed method can provide a 360-degree cold sensation. They also demonstrated statistically significant differences in the effective angle ranges for 360-degree cold sensation between different nozzle-tip directions; parallel (83.0 to 118.4 degree) and center (124.7 to 139.4 degree) nozzle-tip configurations. If we want to attach the nozzles around the chair, the nozzle angle close to 0 degree would be desirable. In contrast, if we want to mount the nozzles on the head-mounted display, the nozzle angle close to 180 degree would be desirable. Therefore, base on the results, the parallel direction would be suitable for the chair, and the center direction would be suitable for the head-mounted display.

However, there are some limitations in this study. In Experiment 2, we followed the basic protocol of the limit method, which collects yes-or-no responses. Therefore, we did not obtain responses related to the detailed distribution over the neck or ratings. In the future, we plan to investigate the detailed distribution of perception. We examined the spatial distribution of the temperature change because the objective of this study is to represent a cold environment. Using the same parameters as in Experiment 1, we measured the delay until the target temperature change occurred at several points away from the jet center. Based on these measurements, we estimated the extent of the delay that occurs at distant points. Based on the measurement result of the temporal change, the delay in changing the temperature at the front target position by 0.17 °C was 1.4 s.This 0.17 °C change is assumed to be the perceptual threshold in Experiment 1. On the other hand, from the perspective of airflow arrival, assuming that a temperature change of 0.1 °C indicates the arrival of the airflow, the delay at the front target position was 0.7 s. We considered this instantaneous cooling. However, details should be investigated in future.

We measured the temperature change in Experiment 1 as a major factor in the perception of environmental cold. However, other factors, e.g. pressure by the airflow and humidity, can be partially related to the cold perception, and affect the perception. In future, we will investigate the multiple factors for 360-degree cold sensation. In this study, the nozzles were arranged symmetrically. However, symmetric arrangement of the nozzles has a possibility to limit the flow exchange and reduce cooling performance based on the increased air pressure around the same distant position, such as the front target position. To examine the effect of the airflow, the usage of the numerical fluid simulation for the fine-tune nozzle placement or airflow velocity would be beneficial. Strong airflow might induce a masking effect, which weaker coldness perception at far locations due to the strong sensation at close locations. In addition, a method that can adjust the distribution and intensity of the cooling with additional nozzles or control methods would be important in a specific scenario. The above investigations are the future works. In the user study, only male participants were involved in the experiment. Thus, the findings of this study may be limited to specific genders and ages. In order to confirm the generalizability of the proposed method, we plan to conduct future evaluations involving a diverse range of participants, such as gender, age, body composition, taking into account device condition and environmental factors, such as airflow pressure, room temperature, and humidity. Furthermore, since the present experiment limited the cold sensation presentation to the neck, we would like to investigate whether similar perceptual effects can be obtained on other body parts, such as the hands or legs.

Since diving is hazardous and requires training, being able to conduct diver training indoors without actually diving is valuable. We plan to build such an application in the future.

## VII. Conclusion

In this study, we proposed a method to represent a 360-degree cold sensation by optimizing the use of jet nozzles, considering the curved geometry of the human body. The measurement results of the temperature change showed that a single nozzle was insufficient to exceed the cold perception threshold, which was 0.17 °C, whereas two nozzles with an inter-nozzle angle of 90 degree or greater successfully exceeded the required temperature change for cold perception. Based on this result, the user study was conducted using two nozzles. We conducted experiments with three levels of airflow velocity under two nozzle-tip angle conditions. One with the nozzle tips parallel and the other with the nozzle tips directed toward the center of the neck. The results confirmed the effect of the nozzle tip direction, while no significant effect of airflow velocity was found. Finally, in device development, regardless of whether the nozzle tip-parallel or center, it is possible to induce cold perception around the entire neck with two nozzles. It would be beneficial to design the device configuration so that the nozzle tip angle can be adjusted as needed.

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