Experimental Setup for Verifying the Funneling Illusion on the Upper Facial Region

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***Abstract*— The sensory funneling illusion refers to a phenomenon where tactile stimuli are perceived at a location where no actual stimulus is presented. This phenomenon can deliver diverse tactile feedback to users in virtual environments using a minimal number of actuators. In this paper, we propose an experiment to validate the occurrence of the sensory funneling illusion on the upper facial region of humans and develop a haptic visor capable of generating this illusion, along with a VR-based perception experiment application. The haptic visor includes four linear resonance actuators, which are attached to each corner of the facial interface of the head-mounted display. The experiment comprises three sessions designed to acclimate subjects to the experimental application, provide preliminary learning of the funneling illusion, and conduct the perception test. Tactile feedback generated by the actuators is transmitted to 12 perception locations in the upper facial region of the subjects. If the proposed experiment verifies the sensory funneling illusion on the face, it is expected that this phenomenon can be leveraged to create more immersive virtual environments with fewer actuators.**

Keywords—haptic feedback, haptic illusion, virtual reality

I. INTRODUCTION

Haptic feedback refers to generating vibrations, forces, or impacts to allow users to feel a sense of touch. Haptic feedback realistically conveys tactile information, increasing users' sense of immersion in various fields that require simulation. In order to provide haptic feedback to users, factors such as force, pressure, moisture, and temperature are required [1]. Recently, haptic devices capable of generating haptic feedback have been widely used in virtual environments. bHaptics has developed and commercialized tactile gloves, tactile suits, and tactile visors that provide haptic feedback to the user's hands, torso, and face, respectively. Hoppe provided the sensation of gravity force to users through a helmet-type haptic feedback device [2]. However, these devices use a large number of actuators to provide tactile feedback at various positions. As the number of actuators increases, issues such as higher cost, increased weight, and high power consumption can arise.

To solve these problems, research using haptic illusions to provide a variety of tactile feedback within limited environments has been actively conducted. Haptic illusion refers to a phenomenon in which physical stimulation provided to a person is perceived in an unexpected form or location. The representative haptic illusions that occur in the human body include the Tau effect, Weber illusion, sensory funneling illusion, and Phi phenomenon.

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The tau effect refers to the phenomenon where temporal intervals influence the perception of spatial intervals. In other words, equally spaced temporal intervals can make spatial distances appear larger or smaller. The Weber illusion refers to a phenomenon where the distance between two points of stimulation is perceived as longer in areas with high spatial resolution, such as the fingertips, compared to areas with relatively low spatial resolution. The sensory funneling illusion refers to a phenomenon where tactile stimulation is perceived in a location where there is no actual stimulation. For example, simultaneous stimulation at multiple points can make the sensation appear to be at a central point. The Phi phenomenon occurs when stimulation is sequentially applied to the skin in several individually separated areas, causing the stimulation to feel continous. By using these haptic illusions, it is possible to provide more diverse tactile feedback to users.

In various studies, haptic illusions have been applied to hands to minimize the number of actuators or to simulate various haptic feedback [3-6]. Lechelt conducted an experiment to check whether the tau effect was effective by changing the temporal relationship between the positions of reference space and comparison space on both forearms [3]. However, they found that no real effects were found, only negligible effects. Longo investigated the size of tactile perception for each part when tactile sensation was provided to the body [4]. As a result, they confirmed that tactile sensation was perceived as greater on the palm than on the forehead. Seo conducted an experiment to determine whether a dynamic vibrotactile sensation could be provided to the palm using two vibrotactile actuators [5]. The results demonstrated that a rich vibrotactile sensation could be provided by applying the funneling illusion. Gilbert conducted an experiment to determine whether number formations could be recognized on the back of the hand using a device that provided a linear, continuous tactile sensation [6]. As a result, he demonstrated that dynamic vibrotactile sensations could be provided on the back of the hand by applying the Phi phenomenon.

There are many instances of applying haptic illusion to hands or arms, but there are few cases of applying them to the face [7-9]. Wolf provided vibrotactile feedback and thermal feedback on the face to improve the sense of presence in virtual environments [7]. In their study, various situations in the virtual environment were expressed tactilely by adjusting the pulse width, intensity, interval, and repetition of the vibrotactile actuator. Kaul performed an experiment to determine whether the funneling illusion occurred on the forehead, chin, and head [8]. The results indicated that the accuracy of localization was highest on the forehead. The accuracy of localization on the side of the head was less than half that of the forehead, suggesting that the side of the head should be avoided when designing tactile systems based on

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the funneling illusion. Additionally, Kaul attempted to provide a "spider sense" sensation by placing vibrotactile actuators on the forehead and chin [9]. However, existing devices that provide haptic feedback to the face encounter commercialization challenges due to the excessive number of vibration actuators required or their limited ability to provide diverse haptic feedback.

Therefore, we aim to develop an eyepatch-type haptic device that reduces the number of actuators to increase energy and cost efficiency while providing a variety of haptic feedback to users. To achieve this, we plan to utilize the funneling illusion, a phenomenon in which tactile perception is felt even in locations where there is no stimulation. However, until now, it has not been verified whether funneling illusion occurs in the upper facial region. In this paper, we establish an experimental environment to verify whether the funneling illusion can be applied to the upper facial region.

II. Experimental Setup

Fig. 1 shows the overall structure of the proposed experimental setup for verifying the funneling illusion on the upper facial region of the human face. The proposed experimental setup consists of a haptic visor, a head-mounted display (HMD) (Meta, Quest 2)(Fig. 2(a)), and a VR perception experiment application. The haptic visor, which includes four vibration actuators, is attached to the facial interface of the HMD to provide haptic feedback to the subject as shown in Fig. 2(b). The VR application proceeds with the subject wearing the HMD equipped with the haptic visor. The haptic visor generates tactile feedback based on information received from the VR application and provides it to the subject.

The subject is able to manipulate virtual objects by moving their hand. When the subject moves their hand, a hand tracker embedded in the HMD tracks its movement and projects it into the virtual environment. Using this functionality, the subject can select a desired virtual button in the VR application by moving their hand and clicking the button by a pinch gesture. When the perception experiment starts, the VR application randomizes the serial number of the perception location. Based on this result, the VR application computes the actuator number, vibration intensity, and duration, then transmits this information to the haptic visor.

The haptic visor is composed of a microcontroller (STMicroelectronics, STM32F407), four linear resonant actuators (LRAs) (JAHWA ELECTRONICS.CO, JHV-10R1), and a UART (Universal Asynchronous Receiver-Transmitter) module. The size of each LRA is 10mm × 10mm × 4mm. The LRA operates at a resonance frequency of 190 Hz and has a vibration acceleration of approximately 2.2 G_{RMS}

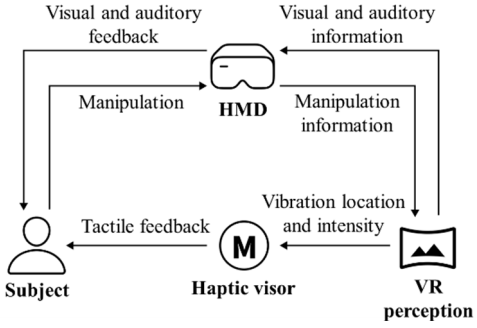


Figure 1. Overall structure of the proposed experimental setup.

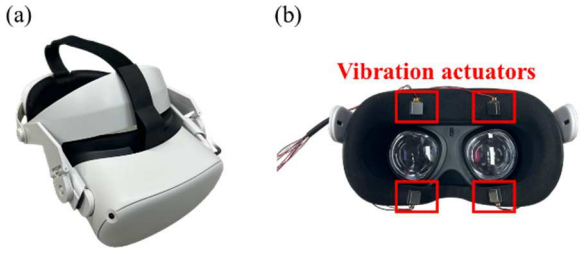


Figure 2. (a) HMD, and (b) its facial interface with four vibration motors.

(G = 9.8 m/s^2, RMS: Root Mean Square) at this frequency. The microcontroller receives the actuator number to be vibrated, the vibration intensity, and the duration from the VR application via UART communication. Based on the received data, the LRA is driven to provide the proper haptic feedback to the subject. The UART communication was configured with a baud rate of 115200 bps, 8 data bits, 1 stop bit, and no parity.

In order to amplify the control signal for operating the LRA, transistor amplification circuits were installed in the haptic visor (Fig. 3). The circuit can amplify a weak signal and drives the actuator only when a voltage above a certain threshold is applied to the base. In this experimental setup, the control signal is generated by PWM (Pulse Width Modulation) and is applied to the base. Therefore, the intensity of the LRA can be adjusted in proportion to the intensity of the PWM signal generated by the microcontroller. Diodes were placed in the circuit to eliminate the back electromotive force generated during the LRA operation.

As shown in Fig. 4(a), four actuators were placed at each corner of the facial interface, and each actuator is assigned a serial number from M1 to M4. These actuators are positioned to generate the funneling illusion, providing haptic feedback to the overall upper facial region. We configured 12 perception locations in the upper facial region, and each assigned a number from P1 to P12, as shown in Fig. 4(b). These locations are distributed evenly to cover the entire facial

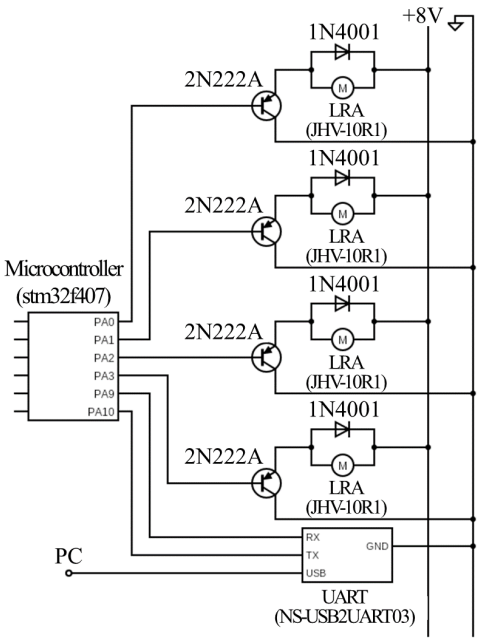


Figure 3. Schematic diagram of the haptic visor.

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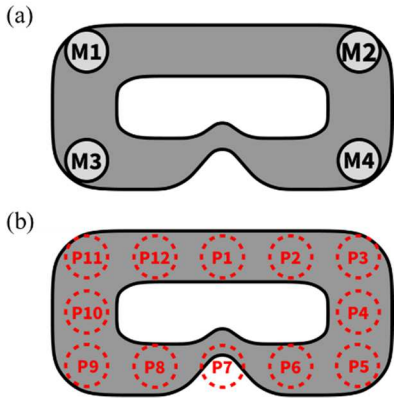


Figure 4 (a) Locations of four LRAs, and (b) 12 perception locations.

interface, ensuring that the haptic feedback can be felt at various points on the subject's upper face.

In order to generate a funneling illusion, the vibration intensity of the vibration actuators should be controlled. Therefore, we divided the vibration intensity of the actuators into 12 steps to create the illusion at various locations [10]. Fig. 5 shows an example of the funneling illusion using two vibration actuators. In Fig. 5(a), the intensity of the two vibration actuators is equal, causing the subject to perceive the sensation at the midpoint between the actuators. It is also possible to move the perceived location by adjusting the intensity ratio of the two actuators, as shown in Fig. 5(b). When only a single actuator is operated, the perceived location is directly on the actuator (Fig. 5(c)). To provide haptic feedback from P1 to P12, the actuators are driven with intensities of {(6, 6, 0, 0), (3, 9, 0, 0), (0, 12, 0, 0), (0, 6, 0, 6), (0, 0, 0, 12), (0, 0, 3, 9), (0, 0, 6, 6,), (0, 0, 9, 3), (0, 0, 12, 0), (6, 0, 6, 0), (12, 0, 0, 0), (9, 3, 0, 0)} [10].

The proposed VR perception experiment application was developed using a game engine (Unity, Unity 3D 2022.3.7f1) and a code editor (Microsoft, Visual Studio 2022). To enable subjects to conduct experiments intuitively, we placed a 3D model of the HMD in the virtual environment and implemented a graphical user interface, as shown in Fig. 6. In the VR application, 12 virtual buttons, representing the perception location, are placed on the 3D model of the facial interface of the HMD.

Subjects can select a desired virtual button by moving their hand, causing the color of the selected button to change to a brighter shade for visual feedback. The movement of the hand

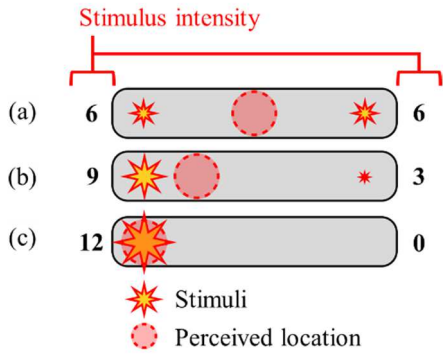


Figure 5. Example of the funneling illusion. (a) Equal intensity, perceived at midpoint. (b) Adjusted intensity ratio, shifted perception. (c) Single actuator, perception on actuator.

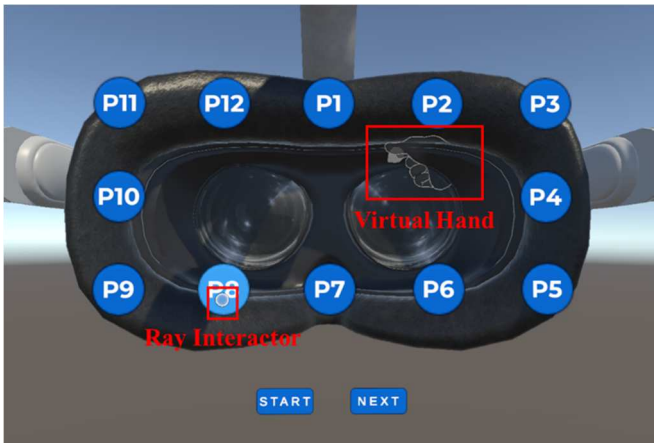


Figure 6. The VR perception experiment application

is intuitively presented to subjects by displaying a virtual hand in the VR application. By visualizing the ray interactor, subjects can easily see the position their hand is pointing to. Clicking the selected button is performed by the pinch gesture. The Oculus Interaction SDK, an external API (Application Program Interface), was used to track the hand movement and capture the pinch gesture. In addition, at the bottom of the virtual environment, a start button and a next button are implemented. The start button initiates a session and the next button moves to the next session. Before starting each session, the subject is provided with instructions through an explanation popup window and voice guidance.

Fig. 7 shows the procedure of the proposed perception experiment for verifying the funneling illusion on the upper facial region. The VR perception experiment application consists of three sessions: Control Tutorial, Haptic Illusion Training, and Haptic Illusion Perception Test. In the first session, each subject conducts a pinch tutorial to become familiar with natural user interactions, such as hand movements and hand gestures. During this session, the subject selects and clicks a virtual button that is activated randomly. In the second session, the subject sequentially experiences the funneling illusion at locations presented from P1 to P12. After this passive experience, the subject can actively feel haptic feedback generated at the desired location by selecting the virtual button. This short-term practice is necessary for a clear perception of the funneling illusion [11-12]. In the last session, we randomly generate haptic feedback according to the perception location, which is then provided to the subject. After receiving the feedback, the subject selects the virtual button closest to where the vibration was felt. During this session, each subject conducts a total of 60 trials, which is computed by conducting five trials for each of the 12 perception locations. The results selected by the subject are stored for analysis of future experimental results.

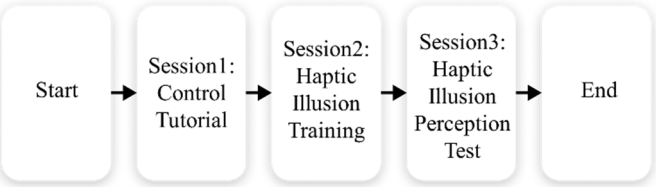


Figure 7. The procedure of the perception experiment.

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III. Conclusion

In this paper, we designed the perception experimental setup for verifying the funneling illusion on the upper facial region of humans. For this experimental setup, we developed the haptic visor and the VR perception experiment application. The haptic visor includes four LRAs that can individually control their intensity and duration. These four LRAs are attached to the corners of the facial interface of the HMD. In this experimental setup, 12 perception locations were configured and evenly distributed on the upper facial region. By leveraging the funneling illusion, we can create haptic feedback where no actuator is physically present by controlling the intensities of two or more actuators and provide it to subjects. In order to conduct the perception experiment intuitively, the VR experiment application, which can be played on the HMD, was developed. The experiment application comprised multiple sessions, including a hand gesture tutorial, a haptic illusion training, and a perception test. The motion of the subject's hand served as the input interface for manipulating the virtual environment. Subjects were able to move their hands and fingers freely. The HMD tracked the hand positions and gestures, representing them within the virtual environment. If the funneling illusion on the upper facial region can be verified, it is anticipated that it will improve the sense of immersion in a VR environment by using fewer actuators to simulate various tactile feedback.

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