2026 IEEE/SICE International Symposium on System Integration (SII)
January 11-14, 2026. Cancún, México

Proposal and Fundamental Evaluation of a Hand Posture Guidance Method Using Air-Jet-Based Force Feedback

H. Ohara, M. Okui, *Member, IEEE*

Abstract— **In the context of preserving traditional performing arts and facilitating efficient motor skill acquisition, there is a need to develop posture guidance methods. Traditionally, visual imitation and verbal instruction have been the primary means of guidance; however, haptic feedback is considered particularly effective for posture instruction and form correction, as it can directly convey movement nuances that are difficult to communicate through visual or auditory channels alone. Although various haptic information transmission devices have been developed, they often present issues such as discomfort caused by reaction force support structures or restrictions on joint range of motion. To address these limitations, we focused on haptic feedback using air jets. Air jets can present forces in arbitrary directions relative to the body part on which the nozzle is mounted, and the approach can be extended to the entire body, enabling posture guidance even for joints involved in complex movements. In this study, we proposed and developed a haptic feedback device for guiding whole-body posture. We demonstrated that the device can provide effective posture guidance and clarified the influence of the frequency characteristics of the presented haptic feedback. Furthermore, we experimentally demonstrated that the system enables complex, multi-joint, and large-range posture guidance.**

I. Introduction

In the context of preserving traditional performing arts and facilitating efficient motor skill acquisition, there is a growing demand for the development of posture guidance methods capable of accurately and effectively conveying the skills and movements of experts. In fields such as dance, martial arts, musical performance, and competitive sports, not only spatial parameters—such as body position and joint angles—but also dynamic elements, including movement speed, timing, and force application, critically influence the success of skill acquisition. Traditionally, visual imitation and verbal instruction have been the primary means of guidance; however, these methods rely heavily on the learner's interpretation, thereby limiting the accurate transmission of subtle motion differences and precise force control [1]. In recent years, methods that utilize motion capture and sensor technologies to measure expert movements and provide feedback to learners based on these data have gained attention [2]. Among these approaches, haptic feedback has been considered particularly effective for posture guidance and form correction, as it can directly convey movement nuances that are difficult to communicate through visual or auditory cues alone.

A wide variety of haptic information transmission devices have been developed. For example, environment-mounted systems such as devices for correcting motion forms using wire and servo motor brakes [3] or multi-touch haptic display devices utilizing touchscreens [4] support the weight of actuators and mechanisms externally, thereby imposing no additional load on the user other than the intended force presentation. This enables low-intensity haptic feedback without discomfort. However, because such devices are fixed to walls, floors, or desks, the user's range of motion is restricted to the vicinity of the device. Exoskeleton-type devices, such as GuideBand [5] using motors and HapticGEAR [6] employing wire-driven actuation, allow for greater freedom of movement and high-output force presentation. Nonetheless, they may restrict the natural range of motion of human joints and cause discomfort at the reaction force support points for haptic feedback. Portable devices, such as fan-based systems [7] or hammer-shaped devices utilizing gyroscopic moments [8], can be used simply by holding a pen-shaped end-effector, thus eliminating the need for wearing any equipment. However, their fixed shape limits their applicability to specific scenarios. Haptic presentation methods that exploit psychophysical phenomena, such as Phantom sensation [9][10] or ultrasonic haptic displays utilizing apparent tactile motion [11][12][13], enable indirect expression by leveraging perceptual illusions. Nevertheless, when illusions are employed, the onset and switching speed of perception can be slower compared to direct haptic presentation, which may degrade performance in scenarios—such as sports—that require rapid feedback.

To address these limitations, we focused on haptic feedback using air jets. Air jets can present forces in arbitrary directions relative to the body part on which the nozzle is mounted. Furthermore, since no reaction force support structure is required, multiple nozzles can be installed without mechanical interference, enabling posture guidance with high degrees of freedom for complex movements. This approach can be extended to the entire body, allowing posture guidance even for joints involved in intricate motions. Previous studies on air-jet-based haptic feedback include elastic property presentation for objects, as in ω-jet [14], and translational guidance devices [15]; however, these were not designed for posture guidance. Although posture guidance for table tennis [16] has been explored, it was limited to racket orientation and did not address body posture and movement. In addition, due to the physical principle of air-jet generation, the output force per nozzle is relatively small—on the order of approximately 1 N—posing a challenge in terms of the magnitude of the haptic feedback provided.

978-1-6654-5784-2/26/$31.00 ©2026 IEEE

In this study, we propose a device for guiding hand posture. The proposed device is designed with a large lever ratio, enabling the presentation of high torque, and incorporates a structure that allows the use of two nozzles for translational force presentation. This design addresses the low output force—a major limitation of conventional air-jet-based haptic feedback systems. The remainder of this paper is organized as follows. Section 2 describes the concept of the proposed method. Section 3 presents fundamental experiments on the characteristics of the nozzles used in the prototype. Section 4 reports guidance experiments targeting the hand, and Section 5 examines whether participants can reproduce complex postures in order to verify the effectiveness of the proposed device for posture guidance.

The main contributions of this paper are summarized as follows.

- Proposed and developed a haptic feedback device equipped with eight nozzles for whole-body posture guidance.
- Experimentally demonstrated that the proposed device can effectively provide posture guidance and elucidated the influence of the frequency characteristics of the presented haptic feedback.
- Experimentally demonstrated that the system enables complex, multi-joint, and large-range posture guidance.

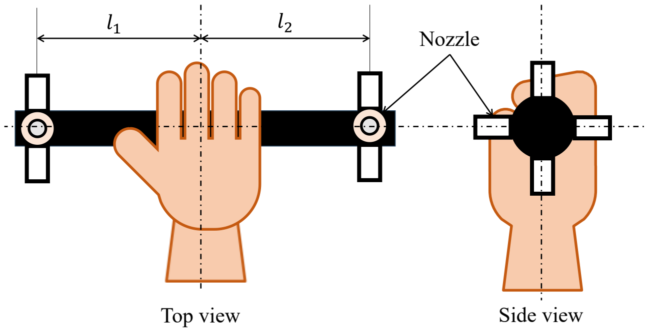

Figure 1. Appearance of the prototype

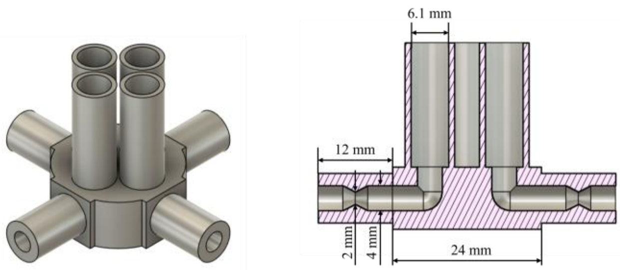

Figure 2. Nozzle used in the experiment

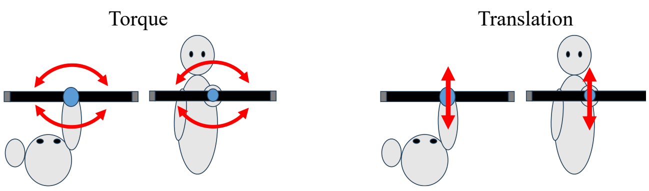

Figure 3. Force feedback pattern of proposed device

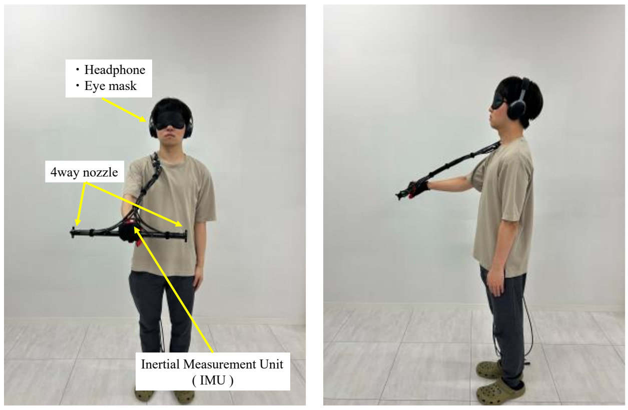

Figure 4. Appearance of the wearer

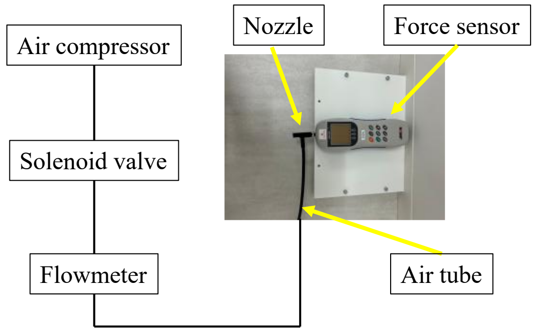

Figure 5. Experimental environment for measuring generating force

II. Proposed Method

A. *Force feedback using air jets*

Guidance using air-jet-based haptic feedback is achieved by attaching a device equipped with air-jet nozzles to the target body part and directing air jets opposite to the desired direction of movement. When the motion deviates in the opposite direction from the intended guidance or instructional target, a reaction force generated by the air jet is presented, enabling the wearer to intuitively understand the desired movement.

B. *Torque Amplification through Lever Ratio*

While most existing devices utilizing air jets have been designed for translational guidance, the present study focuses on torque presentation. For torque, both the air flow rate and the lever ratio can be adjusted, enabling an increase in the magnitude of the presented torque.

The proposed device is a lightweight, rod-shaped apparatus designed to be held in one hand (Fig. 1), with nozzles at both ends, each equipped with four air outlets arranged in a cross configuration (Fig. 2). The haptic feedback patterns of the proposed device are illustrated in Fig. 3. By jetting compressed air in the direction opposite to the intended rotational guidance, a reaction force is generated, which is then used to present torque. The prototype allows guidance in two rotational degrees of freedom (DOF) and two translational DOF, providing a total of four-DOF haptic feedback. The torque generated in this case is expressed by the following equation:

$$T = F_1 l_1 + F_2 l_2 \quad (1)$$

Here, F_1 and F_2 [N] denote the forces generated by the air jets, l_1 and l_2 [mm] represent the distances from the rotational axis, and T [Nm] is the resulting torque. This torque is used to guide the participant's hand.

III. PROTOTYPE

A. Prototype

The appearance of the prototype is shown in Fig. 4. Nozzles are attached to both ends of the prototype, and compressed air is supplied from a compressor (MCP-39SLMA, Monotaro). The weight of the prototype, considering only the portion shown in Fig. 4, is 190 g, and its total length is 476 mm (l_1=l_2=238 mm). The nozzle geometry at each end was designed with reference to a Laval nozzle [17] and fabricated using a 3D printer (Ultimaker S7, Ultimaker B.V.). The throat diameter of the Laval nozzle is 2 mm, and the exit diameter is 4 mm, each connected to an air tube with an inner diameter of 4 mm.

B. Fundamental Performance Evaluation

This section describes the experiments conducted to measure the fundamental characteristics of the fabricated nozzle. The purpose of these experiments was to examine the relationship between the air flow rate delivered by a single nozzle and the resulting generated force.

The experimental setup is shown in Fig. 5. For operating the proposed device, the generated force[N] and the flow rate[L/min] of the nozzle were measured while varying the supply pressure applied to the device. The measurement values were recorded under steady-state conditions after the applied air pressure had stabilized.

For force measurement, the nozzle geometry was modified so that it could be directly connected to a digital force gauge (RZE-5, AIKOH). The flow rate was measured using a flow meter (PF2M721-C8-C, SMC), with the maximum measurable flow rate set to 200 L/min. Measurements were performed at 20 L/min increments.

Subsequently, the relationship between time[s] and generated force[N] was measured under different actuation frequencies. Four frequency conditions were tested: 1 Hz, 5 Hz, 10 Hz, and 20 Hz. The air jets were controlled using a solenoid valve (GEXA-C10C6-4-02C-3, CKD) and an Arduino microcontroller. In these tests, the applied supply pressure was set to 0.50 MPa.

Figure 6 shows the relationship between flow rate and generated force. The force increased with increasing flow rate, reaching 1.26 N at the maximum flow rate of 200 L/min. When the force F [N] is expressed as a quadratic approximation of the flow rate Q [L/min], the relationship is given by Eq. (2).

$$F = 0.00002Q^2 + 0.0033Q \quad (2)$$

Furthermore, since the distance from the center of the device to each nozzle is 238 mm, the maximum torque at the maximum flow rate of 200 L/min is approximately 0.60 Nm, as calculated from Eq. (1).

Figure 7 shows the relationship between nozzle output force and actuation frequency. In this experiment, a command voltage was applied to the solenoid valve at 0.2 s. At 1 Hz and 5 Hz, the maximum nozzle output force was approximately 0.6 N, whereas at 10 Hz and 20 Hz, it was approximately 0.5 N. This reduction in force at higher frequencies is attributed to the shorter valve opening time, which decreases the amount of air released per actuation. The influence of this result on haptic presentation will be examined in the hand-guidance experiments described in Section 4.

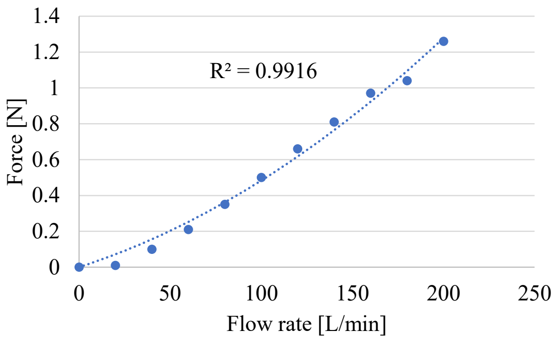

Figure 6. Relationship between flow and force

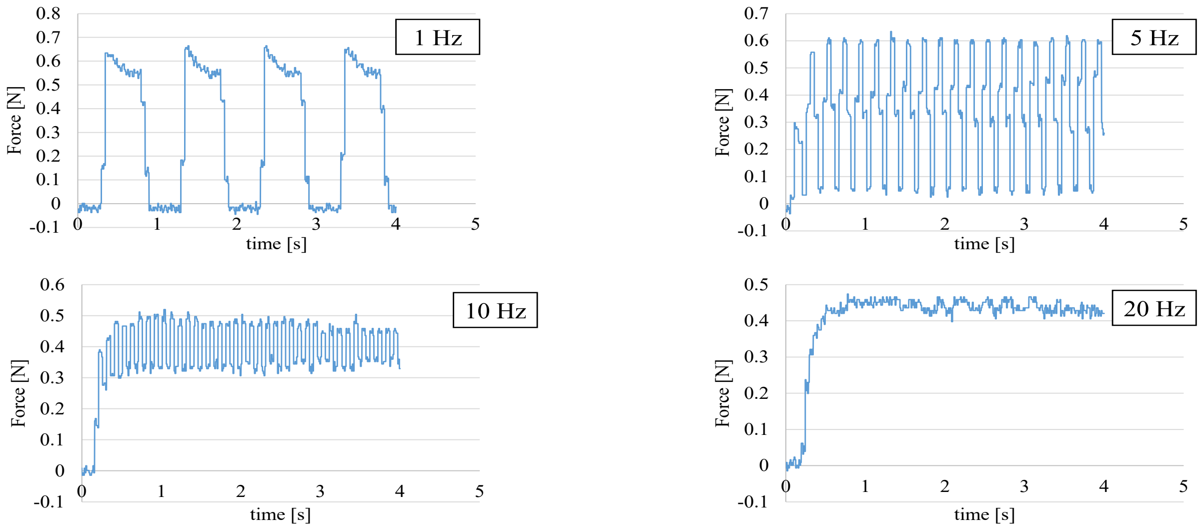

Figure 7. Relationship between nozzle output force and frequency

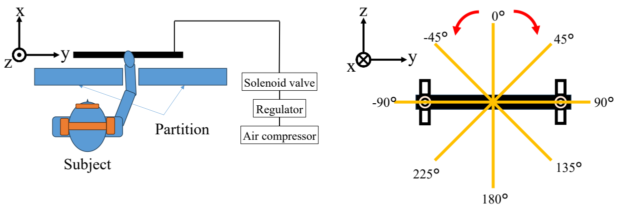

Figure 8. Experimental environment for subjective evaluation of torque direction and angle

IV. Hand Guidance Experiment

A. Purpose of the Experiment

The purpose of this experiment was to verify whether the prototype could guide the hand to arbitrary angles and to examine whether varying the air-jet frequency during operation would affect the ease of guidance. Since translational guidance has already been investigated in a previous study [15], only torque-based guidance was evaluated in this experiment. The experiments in this study have been approved by research on human ethical review of Chuo University (approval number 2025-097).

B. Experiment Summary

The experimental setup is shown in Fig. 8. Each participant wore a glove equipped with an IMU on the back of the right hand, along with headphones and an eye mask. In this condition, air jets were applied continuously until the target angle was reached. The initial angle was defined as 0° when the back of the hand faced the positive z-axis (vertically upward). The target angles were set to 90°, -90°, and 180°, with clockwise rotation about the x-axis defined as positive. A trial under a given condition was terminated when the hand reached within ±10 ° of the target angle or when the participant's hand stopped moving without reaching the target. The air-jet frequencies were set to 1, 5, 10, and 20 Hz, plus continuous jetting, for a total of five frequency conditions. All combinations of target angles and frequencies were tested in 15 randomized sets (covering all combinations). The axis of rotation was limited to the x-axis. The angle of the proposed device was measured using the IMU and an Arduino microcontroller, and the nozzles mounted on the device were controlled by separate solenoid valves according to the direction of rotation. The supply pressure to the nozzles was set to 0.50 MPa. Participants were five male subjects in their twenties. Prior to the start of the experiment, each participant was given a single trial with a random direction of motion to both familiarize them with the task and provide an explanation of the procedure. Data from this preliminary trial were excluded from the results.

C. Experimental Results and Discussion

Under the 0° to 90° condition, all participants were successfully guided except in the 10 Hz case. Under the 0° to −90° condition, all participants were guided successfully at 1 Hz and 20 Hz, while four out of five participants were guided at 5 Hz and under continuous jetting. Under the 0° to 180° condition, four out of five participants were guided successfully at 1 Hz and 5 Hz.

For one of the participants (Subject 3), the hand trajectories for each frequency condition (0° to 90°) are shown in Fig. 9. The times required to reach within ±10° of the target angle are presented in Tables 1, 2, and 3. "–" indicates that the target angle was not reached.

Table 1 shows the time required for guidance from 0° to 90°. The results indicate that, except for the 10 Hz condition of Subject 5, the participants were successfully guided to the target angle, with an average time of approximately 2–9 s. In the 10 Hz condition for Subject 5, the hand was guided from 0° to 70°, but could not be guided further and eventually stopped. This suggests that, in guiding from 70° to 90°, it is necessary to apply a larger torque to the participant.

Table 2 shows the time required for guidance from 0° to −90°. There were four conditions in which the target angle was not reached, which is likely because twisting the elbow joint counterclockwise about the x-axis is more difficult than clockwise rotation. Furthermore, in the present experiment, the IMU was positioned on the back of the hand, and the direction toward −90° placed a greater-than-expected load on the arm in order for the participant's hand to fully reach −90°. In future work, it will be necessary to set appropriate target angles that take into account the difficulty of arm movement in certain directions.

Table 3 shows the time required for guidance from 0° to 180°. Compared with Tables 1 and 2, the number of cases in which the target angle was not reached was the largest. This is attributed to the device becoming unstable due to vibration during the guidance process from 0° to 180°, causing participants to lose the sense of the intended guidance direction and resulting in the hand stopping mid-motion. For example, Fig. 10 shows the case of Subject 2 at 10 Hz, where guidance could not proceed beyond 90°. This suggests that a larger torque should be presented when passing 90°, which could improve the intuitiveness of the guidance.

Figure 9 illustrates the hand trajectories of Subject 3 for each frequency condition (0° to 90°). At lower frequencies of 1 Hz and 5 Hz, periodic oscillations were more pronounced compared with the higher frequencies of 10 Hz and 20 Hz. This is because, at lower frequencies, the participant's hand tended to be pushed back toward the previous angle by recoil after each air jet. In contrast, at higher frequencies and under continuous jetting, such recoil was minimal.

In general, time-varying forces are considered to be more easily perceived by humans [18], and in air-jet-based haptic presentation, it is expected that incorporating modulated, pulsed stimuli in addition to simple continuous jetting could contribute to improved guidance accuracy. However, the results showed that continuous jetting achieved a higher guidance success rate. In the present experiment, the presented torque was sufficiently large, and it can be interpreted that the steady force (continuous jetting), with its longer application time compared to pulsed presentation at varying frequencies, stabilized motor output and consequently reduced the time required to reach the target.

In addition, Subjects 2, 3, and 4 had prior sports experience, and compared with Subjects 1 and 5, who had no such

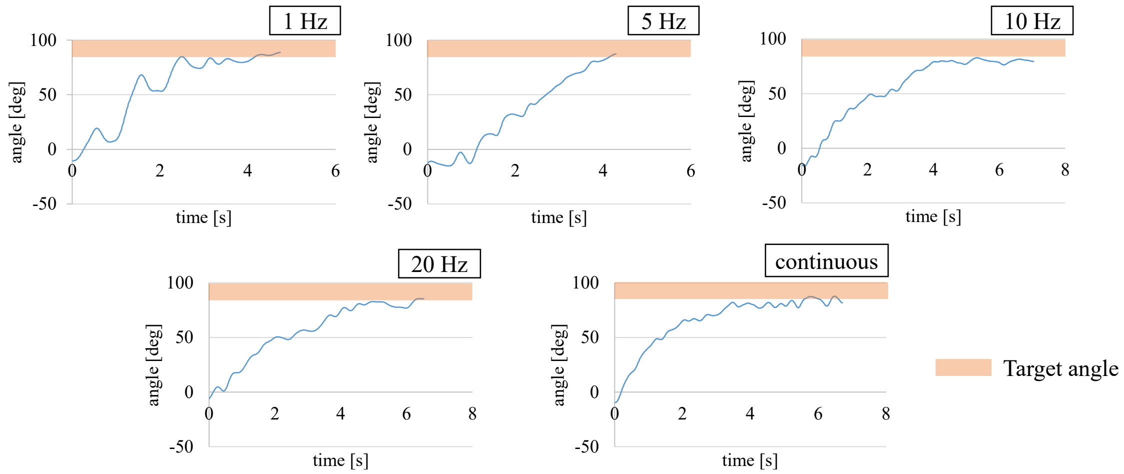

Figure 9. Angle corresponding to each frequency

TABLE I. Elapsed time from 0° to 90° at each frequency

90°	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Average
1	4.14	2.22	2.39	1.43	2.31	2.50
5	6.93	1.68	3.9	2.17	8.53	4.64
10	25.1	5.41	3.97	1.76	-	9.06
20	10.4	1.5	4.49	1.68	5.36	4.69
continuous	3.16	1.13	3.45	1.21	2.5	2.29

TABLE II. Elapsed time from 0° to -90° at each frequency

-90°	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Average
1	4.09	4.07	4.28	3.25	8.14	4.77
5	20.1	2.51	4.06	-	21.2	11.97
10	-	3.35	4.87	6.89	-	5.04
20	29.1	1.3	3.44	1.03	10.1	8.99
continuous	-	4.03	3.19	3	3.54	3.44

TABLE III. Elapsed time from 0° to 180° at each frequency

180°	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Average
1	8.04	25	4.48	8.12	-	11.41
5	16.8	10.1	8.64	11.5	-	11.76
10	-	-	10.9	6.74	-	8.82
20	31.8	18.4	-	-	-	25.10
continuous	-	14.8	7.27	4.73	-	8.93

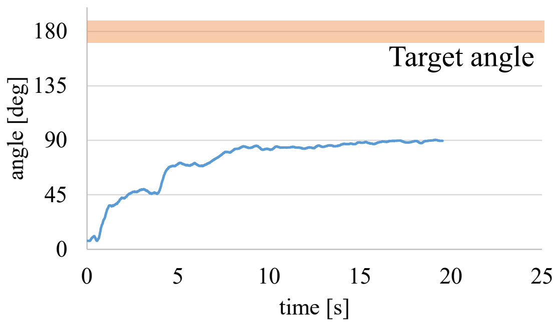

Figure 10. Angle from 0° to 180° at 10 Hz for Subject 2

experience, they exhibited higher success rates in reaching the target angles and required less time for guidance. This suggests that individuals with sports experience may be more sensitive to perceiving haptic cues.

V. Demonstration Experiment

A. Purpose of the Experiment

This device is intended for motor and posture instruction, and therefore must be capable of guiding the wearer's target body part to arbitrary positions. In this experiment, both torque and translational forces were presented in an attempt to guide the participant's hand.

B. Experiment Summary

The participant held the device in the right hand while wearing an eye mask and headphones. The IMU was removed for this experiment. The procedure was as follows (Fig. 11): first, with the initial angle set to 0°, torque was presented to guide the hand to 90°. Once 90° was reached, translational guidance was applied in the rightward direction from the participant's perspective. During the experiment, the operator visually monitored the participant's position and posture and manually controlled the direction of haptic feedback using a manual valve to guide the participant's right hand.

C. Experimental Results and Discussion

Figure 12 shows the guidance process. The participant's right hand was successfully guided according to the planned

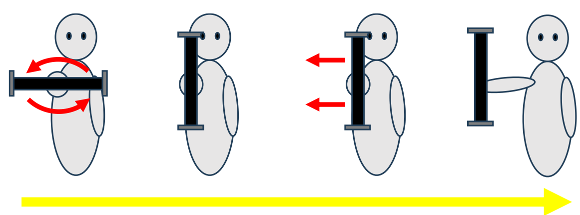

Figure 11. Demonstration route

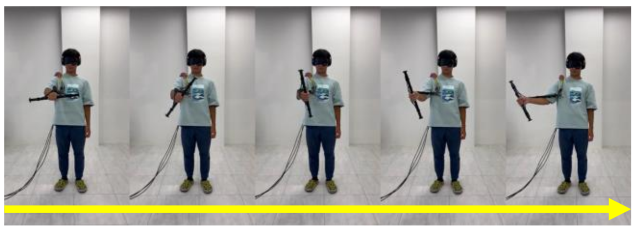

Figure 12. Demonstration scene

procedure. By combining translational and torque presentations, it was confirmed that the system can provide guidance for complex postures involving the shoulder joint. The required time was 1.5 s for torque guidance and 5 s for translational guidance. Translational guidance took longer, likely because it is more difficult to perceive than torque. Therefore, it will be necessary to design the system to increase the output force of the nozzles in order to make translational guidance more perceptible.

VI. Conclusion

In this study, we developed a device that presents torque and translational haptic forces to the hand using air jets, and conducted experiments to evaluate the generated force at different frequencies, assess torque perception, and perform hand-guidance tests. The results confirmed that the device is capable of guiding the hand. In addition, the experiments revealed several challenges in guidance using the proposed device, including cases in which the target angle was not reached, certain angles or directions in which haptic feedback was less perceptible, and specific frequencies that were more suitable for haptic presentation. Therefore, it is necessary to develop a system that increases the output force when the guided motion approaches angles at which haptic perception is reduced.

As future work, we plan to validate the system in the guidance of more complex postures, such as those found in sports forms. Furthermore, we aim to extend the guidance target from the hand to the arm and legs, and to develop a system capable of posture guidance even in the presence of complex joints.

References

[1] S. Schaal, A. J. Ijspeert, and A. Billard, “Computational Approaches to Motor Learning by Imitation,” *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, vol. 358, no. 1431, pp. 537–547, 2003.

[2] J. Lieberman and C. Breazeal, “Tikl: Development of a wearable vibrotactile feedback suit for improved human motor learning,” *IEEE Transactions on Robotics*, vol. 23, no. 5, pp. 919–926, 2007.

[3] Y. Hirata, R. Shirai, and K. Kosuge, “Position and orientation control of passive wire-driven motion support system using servo brakes,” in *Proc. IEEE Int. Conf. on Robotics and Automation (ICRA)*, 2017, pp. 3702–3707.

[4] S. Takanaka, H. Yano, and H. Iwata, “3DOF multitouch haptic interface with movable touchscreen,” *Trans. Virtual Reality Soc. Japan*, vol. 22, no. 3, pp. 325–334, 2017.

[5] D. Weik *et al.*, “Integrating tactile feedback in an acetabular reamer for surgical VR-training,” in *Proc. IEEE Conf. Virtual Reality and 3D User Interfaces (VR)*, 2019, pp. 1227–1228.

[6] N. Kakei, H. Yano, M. Saito, T. Ogi, and M. Hirose, “Development and evaluation of a wearable force display ‘HapticGEAR’ for immersive projection displays,” *Trans. Virtual Reality Soc. Japan*, vol. 5, no. 4, pp. 1113–1120, 2000.

[7] S. Heo, C. Chung, G. Lee, and D. Wigdor, “Tho’s hammer: An ungrounded force feedback device utilizing propeller-induced propulsive force,” in *Proc. CHI Conf. Human Factors in Computing Systems (CHI ’18)*, Montreal, QC, Canada, 2018, pp. 1–11.

[8] M. Yoshie, H. Yano, and H. Iwata, “Development of non-grounded force display using gyro moment effect,” *Trans. Virtual Reality Soc. Japan*, vol. 7, no. 3, pp. 329–337, 2002.

[9] G. von Békésy, “Neural funneling along the skin and between the inner and outer hair cells of the cochlea,” *J. Acoust. Soc. Am.*, vol. 31, no. 9, pp. 1236–1249, 1959.

[10] J. Salazar, K. Okabe, and Y. Hirata, “Path-following guidance using phantom sensation based vibrotactile cues around the wrist,” *IEEE Robot. Autom. Lett.*, vol. 3, no. 3, pp. 2485–2492, 2018.

[11] J. H. Kirman, “Tactile apparent movement: The effects of interstimulus onset interval and stimulus duration,” *Percept. Psychophys.*, vol. 15, no. 1, pp. 1–6, 1974.

[12] T. Iwamoto and H. Shinoda, “Ultrasound tactile display for stress field reproduction – examination of non-vibratory tactile apparent movement,” in *Proc. 1st Joint EuroHaptics Conf. and Symp. Haptic Interfaces for Virtual Environment and Teleoperator Systems (World Haptics Conf.)*, 2005, pp. 220–228.

[13] T. Hashizume and M. Niitsuma, “Pose presentation of end effector using vibrotactile interface for assistance in motion sharing of industrial robot remote operation,” in *Proc. IEEE 28th Int. Symp. Industrial Electronics (ISIE)*, 2019, pp. 1186–1191.

[14] M. Okui, T. Masuda, T. Tamura, Y. Onozuka, and T. Nakamura, “Wearable air-jet force feedback device without exoskeletal structure and its application to elastic ball rendering,” in *Proc. IEEE/ASME Int. Conf. Advanced Intelligent Mechatronics (AIM)*, Boston, MA, USA, 2020, pp. 276–281.

[15] R. Sawahashi, T. Yasui, M. Okui, R. Nishihama, and T. Nakamura, “Body guidance by force feedback device using air jet,” *Trans. Virtual Reality Soc. Japan*, vol. 27, no. 3, pp. 264–273, 2022.

[16] R. Suzuki, R. Sawahashi, R. Nishihama, and T. Nakamura, “Proposal of posture guidance method using air jetting with table tennis racket type device,” in *Proc. IECON 2022 – 48th Annu. Conf. IEEE Industrial Electronics Society*, 2022, pp. 1–6.

[17] P. Agarwal, J. Fox, Y. Yun, M. K. O’Malley, and A. D. Deshpande, “An index finger exoskeleton with series elastic actuation for rehabilitation: Design, control and performance characterization,” *Int. J. Robot. Res.*, vol. 34, no. 14, pp. 1747–1772, 2015.

[18] S. Murakami, S. Kurimoto, H. Yoshikawa, and M. Nakamura, “Mechanosensory mechanisms in human skin: Relevance to tactile perception in dermatology,” *Skin Res. Technol.*, vol. 28, no. 5, pp. 778–789, 2022.