

Exploring the Effects of Spatially Distributed Cheek Pressure Stimulation on Virtual Experiences

Ryu Kimura¹, Fumihiko Nakamura¹, Asako Kimura¹, and Fumihisa Shibata¹

¹ Ritsumeikan University, Japan

Abstract

In Virtual Reality (VR), haptic stimulation is promising approach to enhancing virtual experiences. However, facial haptics remain underexplored, particularly the cheeks, which have the potential to improve presence and to foster affective interaction. This study explores the effects of spatially distributed cheek pressure stimulation on virtual experiences. We developed a facial stimulation system by attaching six servo-driven linear actuators to a head-mounted display, enabling the application of pressure to multiple points on the cheek. Two user studies were conducted under three conditions: visual-only, single-point stimulation, and multi-point stimulation. The first study examined the effects of multi-point cheek pressure stimulation on presence and emotional responses when interacting with non-human virtual entities. The second study assessed its impact on presence, emotional responses, and social presence during interactions with human-like avatars. Results showed that cheek pressure stimulation significantly enhanced presence and social presence, and elicited higher emotional arousal. Furthermore, temporal variations in cheek pressure effectively improved valence in playful interaction with an avatar. Comparisons between single-point and multi-point stimulation revealed only minor differences, indicating limited additional benefits of multiple pressure points. However, participants' self-reports suggest that applying pressure to multiple points on the cheek is more likely to increase the perceived overall force intensity, rather than producing a sensation of distinct stimulation points.

CCS Concepts

• **Human-centered computing** → *Virtual reality; User studies; Haptic devices;*

1. Introduction

Virtual Reality (VR) has become increasingly prevalent across diverse domains such as entertainment, education, and professional work, with the boost of the widespread of consumer head-mounted displays (HMDs). A key factor in enriching the VR experience is the presence, which allows users to perceive the computer-generated environment not merely as a simulation, but as a lived and embodied reality. Beyond the presence, social presence plays an equally essential role in shaping the quality of interaction. It enables users to perceive other humans or virtual agents as real, socially available counterparts, thereby enhancing the overall depth of interaction between the users and virtual agents.

To enhance both presence and social presence in virtual environments, haptic feedback plays a crucial role [WGL*19, JBA*24]. The addition of haptic cues to visual and auditory stimuli establishes visuo-haptic consistency, enriches perceptual realism, and elicits stronger emotional responses, thereby reinforcing the presence. Moreover, with respect to social presence, the incorporation of haptic signals alongside visual and auditory channels facilitates affective touch and tactile expressiveness, enabling users to experience co-presence and fostering a heightened mutual awareness in interpersonal and human-agent interactions.

Most haptic VR studies have primarily focused on the hands due to their high tactile sensitivity and frequent use in object and agent interactions [WYL21]. In contrast, facial haptics has received limited attention, despite the face's sensitivity to haptic stimuli and its crucial role in interpersonal communication. Prior studies have shown that presence and emotional responses were enhanced by ambient haptic cues [RJK*17, WRHR19, SSH22] and tangible cues [WLT*20] to the face. However, the effect of multi-point pressure stimulation on the face, which offers spatially distributed force feedback, remain largely underexplored, leaving open questions about its potential to enrich virtual experiences.

In this paper, we explore the effect of multi-point facial pressure stimulation, enabling to offer changes on spatially distributed locations, on virtual experiences. We developed an HMD-based system equipped with six servo-driven linear actuators attached to the headset, providing pressure feedback at six points on the cheeks. We conducted two experiments comparing multi-point stimulation with non-haptic and single-point conditions. Experiment 1 examined the effect cheek pressure stimulation on presence and emotional responses in three situations: interacting with a virtual animal, with visible objects, and with hard-to-see objects. Experiment 2 assessed the impact on presence, emotional responses, and social

presence in three situations: playing with a virtual character, being examined by a doctor avatar, and playing with a virtual avatar.

This study investigates the following research questions (RQs):

- RQ1: Does cheek pressure stimulation enhance presence and emotional responses?
- RQ2: Does cheek pressure stimulation improve social presence?
- RQ3: Does spatially distributed cheek pressure stimulation offer a better experience than single-point stimulation?

Our contributions are as follows: (1) We demonstrated that cheek pressure stimulation enhanced presence, particularly spatial presence and realism, although it was not effective for ambient information such as raindrops. (2) We showed that cheek pressure stimulation improved social presence, and, the results suggest that expressive cheek pressure stimulation increases social presence in a context-dependent manner. (3) We found that although spatially-distributed cheek pressure stimulation offered few advantages over single-point stimulation, in socially positive situations, spatially expressive stimulation contributed to greater pleasantness.

2. Related Work

2.1. Haptic Feedback for Emotional Responses

In human-computer and computer-mediated interaction, haptic feedback has been utilized to enrich experiences. Prior studies demonstrated that pressure and force feedback to the hands enhanced presence [SRGS00] and emotional responses [BFRS10].

Beyond the hands, the face, highly sensitive to haptic stimuli and socially significant, has been explored as a feedback target. In particular, the cheeks and lips, both sensitive and socially expressive, have received attention. Cheek stimulation has been shown to alleviate stress [SU17] and enhance communication via phones [HMK09, PLN10, PBN12, HSH*12, PN13]. For example, Hashimoto et al. mapped hand gestures to vibrotactile cheek patterns [HMK09], while CheekTouch transmitted partners' finger gestures as vibrotactile cues, enriching couples' communication [PLN10, PBN12]. Hoggan et al. converted pressure to a mobile phone into cheek vibrations, improving presence and emotion [HSH*12]. POKE proposed an interpersonal interaction technique using a poking actuator embedded into a phone [PN13]. For lips, ultrasonic haptics have been shown to evoke stronger emotional responses [LSWL24, JFK*21], and kissing devices have also been developed [SPR*12].

Overall, facial haptic feedback has proven effective in evoking emotional responses in interpersonal and human-computer contexts. However, most studies employed single-point pressure stimulation, leaving spatially distributed pressure largely unexplored. Our work addresses this gap by examining its effect on emotional responses through six scenarios.

2.2. Haptic Cues in VR Interaction with Humans and Agents

When people interact with humans or virtual agents in VR environments, the effects of haptic feedback on social experiences have been investigated [JBA*24, BTPT19]. Prior studies have reported that vibrotactile cues from virtual agents enhanced realism and emotional responses [KMW19], while vibrotactile with

pressure cues strengthen human-agent bonds [HSAA*23]. Similarly, the use of pressure, thermal feedback, and haptic textures improved social expressiveness and emotional closeness [KC24]. Force feedback during VR collaboration was also found to enhance presence and social presence [Sal10] and effectively convey emotions [BYB*07]. Hoppe et al. demonstrated that social touch with an artificial hand increased perceived agency and co-presence with virtual agents [HRN*20]. Furthermore, force feedback induced stronger emotional responses and co-presence than vibrotactile cues when participants were touched by virtual agents [AHJ*16].

Thus, these studies have shown that haptic feedback across various modalities enhanced social presence in interactions with both humans and agents. However, prior work has primarily focused on social touch applied to the hands or body, while the effects of facial stimulation remain underexplored. In particular, it is still unclear how cheek pressure stimulation influences social presence. Our study investigates the effect of cheek pressure stimulation on social presence in human-agent interaction.

2.3. Head/Facial Haptics in VR

Since the head is highly sensitive to haptic stimuli, many studies have explored haptic feedback to the head for enhancing virtual experiences. In particular, haptic actuators such as vibrotactors [KRMS21, CCL*21], air jets [LYM*20], robotic arms [CL22], and fans [WNS*22, HOSK21] have been applied around the head to enrich navigation, immersion, and sensory realism.

Facial haptics have received particular attention due to their higher sensitivity and social relevance. Ultrasonic feedback to the mouth improved presence, particularly realism and visuo-haptic consistency [SSH22], while presence and immersion was enhanced by multisensory stimulation to the face, such as thermal and wind cues [RJK*17, RJTNT*18], vibrotactile and thermal cues [WRHR19]. Moreover, facial haptics have been leveraged for improving teleportation sensation with wind [TCL*22], alleviating phantom limb pain with vibrotactile stimulation [ISO*17], and improving driving experience with vibrotactile cues [YML*23].

Beyond tactile cues, force and encountered-type haptic feedback have also been applied to the face. Previous studies have introduced various stimulation, such as normal force [CTT*18], skin stretch [WHH*19], cheek tap [LYC*19], combination of cheek push and galvanic vestibular stimulation [TNS*20], and suction stimulation [KKNK18], to improve the virtual experience. To offer localized stimulation to the cheek, robotic arms have been employed. Virtual Whiskers provided spatial cues with HMD-integrated two robotic arms [NVS*22]. HapticSnakes employed a wearable robotic arm to present haptic feedback to an HMD user [ASJR*20]. FaceHaptics provided multisensory cues with a single robotic arm attached to the HMD to improve the presence and emotional responses [WLT*20].

As discussed above, head and facial haptics significantly enhance presence, immersion, and emotional responses in VR. However, pressure stimulation has been rarely examined, and prior work mostly relied on single-point feedback. The effects of multi-point facial pressure on virtual experience remain largely unexplored. In our study, we explore how multi-point facial pressure stimulation,

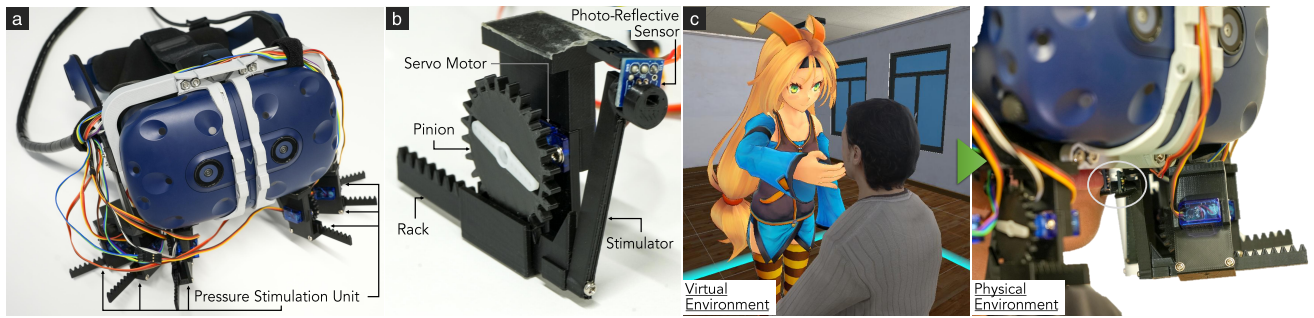


Figure 1: Facial Haptic Stimulation Device. (a) Device Overview. (b) Pressure Stimulation Unit. (c) Pressure Stimulation to User's Cheek Triggered by Haptic Event, such as Touch by an Avatar (©UTJ/UCL), in Virtual Environment.

that is, spatially distributed facial pressure stimulation, affects presence, emotional responses, and social presence.

3. Experiment Overview

To address the RQs, we conducted two experiments involving walkthrough experiences with haptic cues applied to a large area of the cheeks. Experiment 1 focused on environmental factors, such as virtual animals, virtual objects, and ambient information. The goal was to examine how cheek pressure stimulation influenced presence and emotional responses shaped by information from the virtual environment. Experiment 2 focused on interactions between users and virtual agents, such as cheek-squishing by characters and avatars, and examinations by a doctor. The goal was to investigate the impact of cheek pressure stimulation delivered through virtual agents on presence, emotional responses, and social presence induced by cues provided from agents and virtual environment.

In both experiments, we used the common device and software, and employed the same conditions, procedures, participants, and statistical analysis protocols.

3.1. Facial Pressure Stimulation Device

We developed a device that provided multi-point pressure stimulation to the cheeks of an HMD user by modifying an HMD (HTC VIVE PRO) (Figure 1a). To achieve spatially-distributed multi-point stimulation without causing fatigue due to the device weight, we stimulated three points on each cheek. Our device consists of six pressure stimulation units (Figure 1b), a microcomputer (Arduino Nano Every), and a pulse width modulation (PWM) servo driver (NXP PCA9685). Each stimulation unit employed a rack and pinion mechanism, and comprised a rack, a pinion, a stimulator, a servo motor (Tower Pro Micro Servo SG51R), and a photo-reflective sensor (Kodenshi SG-105). The rack, the pinion, and the stimulator were fabricated using a 3D printer. The pinion was mechanically coupled to the servo motor. All units were attached to the bottom of the HMD using 3D-printed brackets. The servo motors of all units were connected to the PWM servo driver, which was powered by a 5V AC adapter. The servo driver was controlled by the microcomputer, which communicated with a computer running the virtual environment via USB serial connection.

The pressure stimulation unit converted the rotational motion of the servo motor into linear motion through a rack-and-pinion mechanism, thereby presenting a pressure force (Figure 1c). The stimulator, located at the end of the rack, was attached with a screw that allowed adjustment of its tilt angle to control the stimulation position. Each pressure stimulation unit employed a stimulator of a different height: 50 mm for units positioned near the lip, 60 mm for those at the center of the cheek, and 70 mm for those near the ear. The tip of each stimulator was circular with a diameter of 10 mm and embedded with a photo-reflective sensor, which measured the distance between the stimulator tip and the participant's skin. The rack extension length l_{rack} was computed as:

$$l_{rack} = D_{pinion} \times \pi \times \theta_{servo} / 2\pi \quad (1)$$

where θ_{servo} denotes the servo rotation angle, and D_{pinion} represents the diameter of the pinion's reference circle. In our implementation, D_{pinion} was 36.0 mm; the pinion had 24 gear teeth, the rack had 14 gear teeth, and the total length of the rack was 82.0 mm. The minimum controllable rack extension was 0.57 mm. The controllable range of rack extension was 0.00–56.52 mm. A preliminary study was conducted to determine the maximum force that could be applied without causing discomfort, and the results indicated that a rack extension of 10.00 mm was the upper limit that did not induce discomfort.

For safety, the microcomputer monitored the rack extension using photo-reflective sensors embedded in each linear actuator. If a sensor value exceeded a predefined threshold indicating a potential risk of injury, the microcomputer immediately retracted all actuators to their initial positions and terminated actuator control.

3.2. Virtual Environment

We used Unity 2021.3.20f1 to develop the virtual environments for both experiments. When a haptic event occurred in the virtual environment, it sent control commands to the device to trigger cheek pressure stimulation.

3.3. Experimental Condition

In both experiments, we compared three conditions: visual-only, single-point stimulation, multi-point stimulation (Figure 2). In the visual-only condition, no pressure stimulation was applied. In the

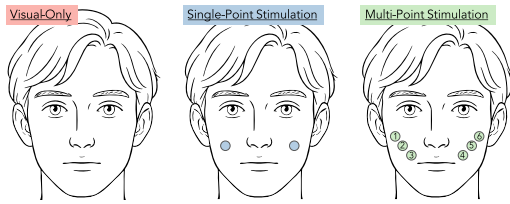


Figure 2: *Experimental Condition. (Left) Visual-Only Condition. No haptic stimulation was provided. (Center) Single-Point Stimulation Condition. Pressure stimulation was provided to only a single point for each cheek. (Right) Multi-Point Stimulation Condition. Pressure stimulation was provided to three points for each cheek.*

single-point stimulation condition, pressure stimulation was provided to only a single location of each cheek. In multi-point stimulation condition, pressure stimulation was provided to three locations on each cheek. By comparing the visual-only condition with single- and multi-point stimulation conditions, we aimed to investigate the effect of cheek pressure stimulation. Furthermore, by comparing the single- and multi-point stimulation conditions, we sought to examine the advantages of spatially distributed cheek pressure stimulation over single-point pressure stimulation.

3.4. Procedure

The experiment began with a task briefing. At that time, the experimenter explained the scenario for each task. The experimenter instructed the participant to sit on a chair, wear earplugs, and then put on our device. Then, the participant wore noise-canceling headphones (SONY WH-1000XM5 B) to reduce noise from the device's servos. The experimenter calibrated the position of the stimulator tip against the participant's cheek surface and then retracted it by 3.0 mm from the skin. After the setup, the participant experienced the task with virtual entities and agents under a specific condition, and then completed a questionnaire presented through the HMD using the Virtual Reality Questionnaire Toolkit (VRQT) [FKTK20], with responses entered via VR controllers. Upon completing the questionnaire, the participant removed the device and headphones and took a two-minute break. The device and headphones were then worn again, and the participant experienced virtual entities and agents under a different condition. All participants experienced all tasks under all conditions, with the order of conditions and tasks randomized for each participant. This study was conducted with an experimental protocol approved by the research ethics committee at our institute.

3.5. Participant

We recruited 24 participants (17 males, 7 females; $M = 22.9$ years, $SD = 1.3$) from our university. All participants had VR experience, and all reported using it more than once a week.

3.6. Statistical Analysis

We first tested the normality of the questionnaire data using the Shapiro–Wilk test. If the data were non-normal ($p < .05$), we applied the Friedman test, followed by pairwise Wilcoxon tests with

Holm correction. If the data were normal, we conducted a one-way ANOVA, followed by Tukey's HSD test.

4. Experiment 1

This experiment explored the effect of cheek pressure feedback on virtual experience in interacting with virtual non-human entities. In this experiment, we evaluated the sense of presence and emotional responses in three tasks involving haptic stimulation to the cheek for analyzing the characteristics of cheek haptic stimulation.

4.1. Task

The participants experienced three scenes involving three types of entities, a dog, leaves, and raindrops. We assumed that non-human haptic sources can be categorized into creatures (e.g., dogs, spiders), visible objects (e.g., leaves, balls), and ambient cues (e.g., raindrops, air vortices), and designed scenes accordingly.

In Task 1-1, participants experienced being rubbed by a virtual dog while seated on a sofa. At the beginning, the dog approached the participant's right side and rubbed the right cheek several times. In the single-point stimulation condition, pressure stimulation was applied by extending the rack 10 mm from the skin surface at a single location. In the multi-point stimulation condition, the same 10 mm force was applied, but the stimulation location varied. For example, all locations were activated simultaneously, or only the near-ear location was stimulated.

In Task 1-2, participants rode in the right rear seat of an open car moving through a grassland with scattered trees. This task was inspired by a previous study [WLT*20]. As the car moved forward, tree leaves occasionally brushed against the participant's cheek. Each time this occurred in the virtual environment, pressure stimulation was delivered. In the single-point stimulation condition, a 10 mm force was applied once per collision event. In the multi-point stimulation condition, pressure stimulation was applied across multiple cheek locations, sometimes activating only one of the three positions, again following the same procedure as in Task 1-1.

In Task 1-3, participants experienced raindrops falling on their cheeks while sitting on a bench, following a similar task used in a previous study [WLT*20]. At first, the sky darkened and rain began to fall in the virtual environment. Although raindrops were visible, individual drops were difficult to perceive visually. Participants instead felt the raindrops on their cheeks. In the single-point stimulation condition, stimulation was randomly applied to one location on either the left or right cheek at 0.2 s intervals. In the multi-point stimulation condition, stimulation was applied to random locations with randomized force corresponding to a rack extension of 2.00–6.00 mm. The interval between stimulation was randomly selected from 1.5, 2.0, or 2.5 s.

Each task duration was thirty seconds. The tasks were presented in a counterbalanced order across participants.

4.2. Questionnaire

We evaluated presence and emotional responses using questionnaires. Table 1 and Table 2 show the items on presence and emotional responses, respectively. Twelve items for general presence,



Figure 3: Tasks for Experiment 1. (Left) Scene of Task 1-1. A dog rubbed the participant’s cheek with its nose. (Center) Scene of Task 1-2. The participant rode in an open car and moved forward, during which the leaves of trees brushed against the participant’s cheek. (Right) Scene of Task 1-3. The participants sat on a bench in the rain and felt raindrops on the cheek.

Table 1: Questionnaire on Presence. P1, P2-P5, P6-P9, and P10-P12 correspond to general presence, spatial presence, involvement, and realism, respectively.

- P1 In the computer generated world I had a sense of "being there."
- P2 Somehow I felt that the virtual world surrounded me.
- P3 I felt like I was just perceiving pictures.
- P4 I had a sense of acting in the virtual space, rather than operating something from outside.
- P5 I felt present in the virtual space.
- P6 How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?
- P7 I was not aware of my real environment.
- P8 I still paid attention to the real environment.
- P9 I was completely captivated by the virtual world.
- P10 How real did the virtual world seem to you?
- P11 How much did your experience in the virtual environment seem consistent with your real world experience ?
- P12 The virtual world seemed more realistic than the real world.

Table 2: Questionnaire on Emotional Responses. ER1, ER2, and ER3 correspond to valence, arousal, and dominance, respectively.

- ER1 How positive or negative was your emotional response during this experience?
- ER2 How activated did you feel during this experience?
- ER3 How in control did you feel during this experience?

spatial presence, involvement, and realism were extracted from the igroup presence questionnaire [TLY*24], and the participants rated them on a 7-point scale. For the emotional responses, we assessed the valence, arousal, and dominance with Self-Assessment Manikin (SAM) [BL94], with each item rated on a 9-point scale.

4.3. Result

Figure 4a indicates the result of the presence questionnaire, and Figure 4b shows the result of emotional response questionnaire. In the statistical analysis, we conducted a parametric test for ER3 of Tasks 1–3, as the data were normally distributed; non-parametric

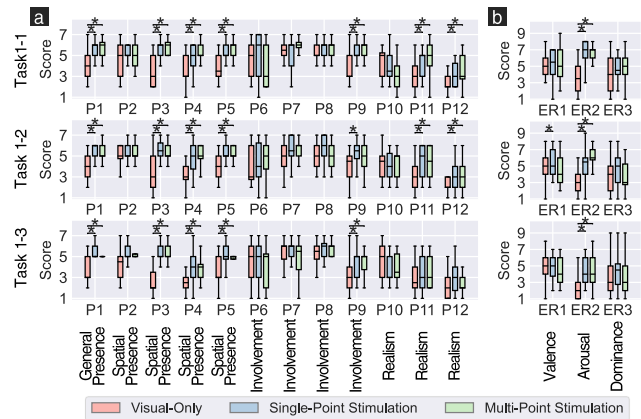


Figure 4: Result of Task 1-1, 1-2, and 1-3. * indicates $p < .05$. (a) Result of presence questionnaire. (b) Result of emotional responses questionnaire.

tests were applied to the other items. Detailed statistical test results, including normality tests, parametric and non-parametric tests, and post-hoc analyses, are provided in the Supplemental Material.

Both pressure conditions showed higher presence (P1, P3–P5, all tasks), involvement (P9, Tasks 1-1 and 1-2), and realism (P11–P12, Tasks 1-1 and 1-2) scores than the visual-only condition. The single-point condition also differed from the visual-only condition in involvement (P9, Task 1-2) and valence (ER1, Task 1-2), and both pressure conditions yielded higher arousal (ER2, all tasks) across all tasks.

5. Experiment 2

Experiment 2 assessed how cheek pressure stimulation affected virtual experience in interacting with human-like virtual agents. We evaluated presence, emotional responses, and social presence in three different tasks including haptic cues to the cheek for analyzing the characteristics of cheek haptic stimulation.

5.1. Task

The participants experienced three different situations involving human-like virtual agents. We assumed that, in social interactions

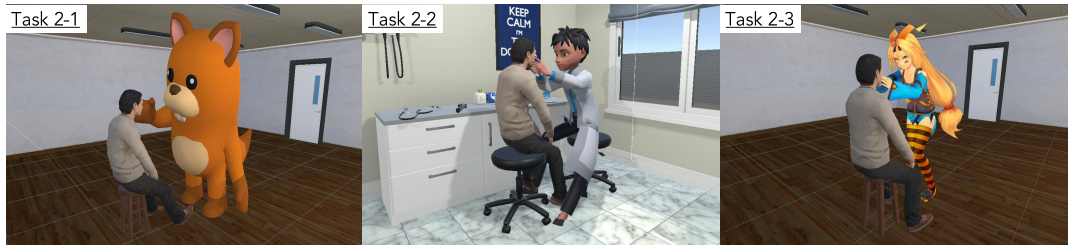


Figure 5: Tasks for Experiment 2. (Left) Task 2-1. A character touched to the participant's cheek with its hands. (Center) Task 2-2. A doctor avatar examined the participant's condition by touching the cheek. (Right) Task 2-3. A human-like avatar (©UTJ/UCL) squished the participant's cheek.

in virtual environments, users may encounter a variety of situations; among them, being touched by another person can be interpreted as either playful interaction or part of a task such as a medical examination. Based on this assumption, we designed three tasks.

In Task 2-1, participants, seated on a chair, interacted with a human-like character. At the start, the character alternately touched the participant's left and right cheeks. In the single-point stimulation condition, pressure stimulation was applied to one location on each cheek, with the applied force corresponding to rack extensions of 6 mm, 2 mm, 10 mm, and 4 mm, each lasting 1.0 s. In the multi-point stimulation condition, the same sequence of forces was applied simultaneously to three locations on each cheek. One cycle consisted of left-right alternations, repeated three times per task.

In Task 2-2, participants experienced a scenario in which a doctor avatar palpated their cheeks to check their condition. At the beginning, the doctor touched both cheeks simultaneously, then only the left cheek, and finally only the right cheek. During contact, pressure stimulation was continuously applied with rack extensions of 8 mm, 2 mm, 10 mm, and 4 mm, each lasting 0.5 s. In the single-point condition, one location per cheek was stimulated. In the multi-point condition, the sequence proceeded as follows: for both cheeks, stimulation was applied in order from the ear-side points, to the central points, and then to the lip-side points.

In Task 2-3, participants interacted with Unity-chan, a highly human-like avatar. At first, the avatar touched both cheeks simultaneously and began to squish the participant's cheeks. In this task, the stimulation parameters were randomized. Specifically, the rack extension ranged from 2 mm to 6 mm, and the duration of each touch was randomly set to 0.5, 1.0, or 1.5 s. In the single-point condition, stimulation was randomly applied to either one cheek or both cheeks. In the multi-point condition, stimulation was randomly applied to multiple cheek locations, which varied between single-point, dual-point, and full-cheek activation patterns.

Each task lasted approximately 30 seconds. The task order was randomized for each participant, with counterbalancing applied across the entire participant group.

5.2. Questionnaire

In addition to the questionnaire on presence ((Table 1) and emotional responses (Table 2), we employed a questionnaire on social presence (Table 3). To assess the social presence, we selected

Table 3: Questionnaire on Social Presence. SP1-SP4, SP5, SP6, SP7-SP8, SP9-SP11 are the items regarding co-presence, allocational attention, Perceived Affective Understanding (PAU), Perceived Emotional Interdependence (PEI), and Perceived Behavioral Interdependence (PEI), respectively.

SP1	I noticed the partner.
SP2	My partner's presence was obvious to me.
SP3	My partner caught my attention.
SP4	I caught my partner's attention.
SP5	I remained focused on my partner throughout our interaction.
SP6	I could describe my partner's feelings accurately.
SP7	I was sometimes influenced by my partner's moods.
SP8	My partner was sometimes influenced by my moods.
SP9	My behavior was often in direct response to my partner's behavior.
SP10	I reciprocated my partner's actions.
SP11	My behavior was closely tied to my partner's behavior.

items related to co-presence, allocational attention, perceived affective understanding, perceived emotional interdependence, and perceived behavioral interdependence, from Networked Mind Social Presence Measure [HB04].

5.3. Result

Figure 6a, Figure 6b, and Figure 6c indicate the results of presence, emotional responses, and social presence, respectively. In the statistical analysis, we conducted parametric tests for ER1 and ER2 of Task 2-1, SP4 of Task 2-2, and ER1-ER3 of Task 2-3, as the data were normally distributed; non-parametric tests were applied to the remaining items. Detailed results of the statistical analyses for Experiment 2 are reported in the Supplemental Material.

Both pressure stimulation significantly improved presence (P1, P3-P5), immersion (P9), realism (P11), arousal (ER2, all tasks), allocational attention (SP5), PAU (SP6, Tasks 2-2 and 2-3), PEI (SP8), and PBI (SP9-SP11) in all tasks. Compared with the visual-only condition, the single-point condition increased realism (P10), valence (ER1, Task 2-2), and co-presence (SP3, Task 2-1), whereas the multi-point condition decreased realism (P10, Task 2-1) but increased valence (ER1, Task 2-3). A significant difference between the two pressure conditions appeared for realism (P10, Task 2-2).

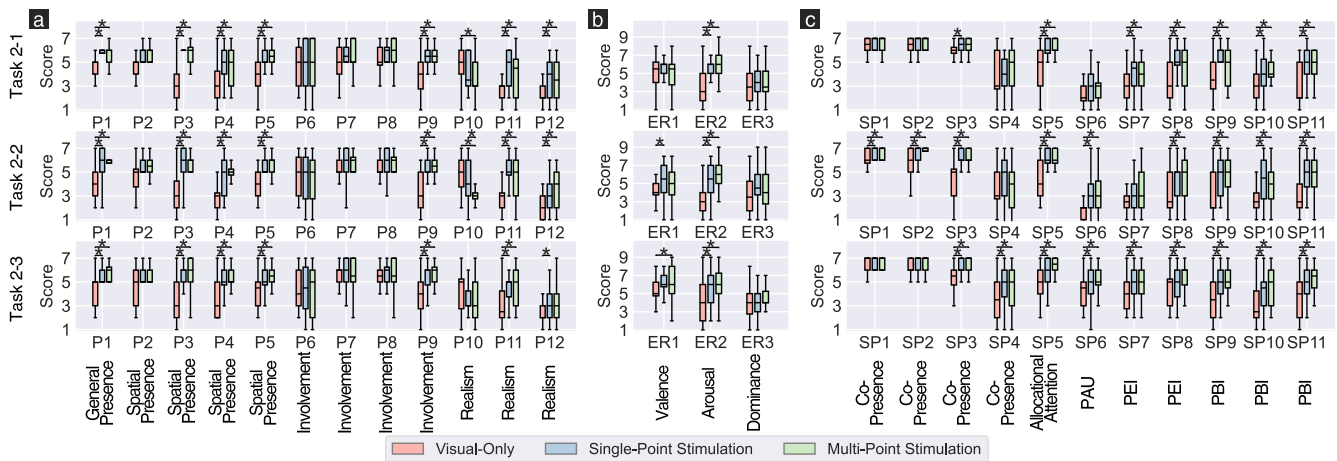


Figure 6: Result of Task 2-1, 2-2, and 2-3. * indicates $p < .05$. (a) Result of presence questionnaire. (b) Result of emotional responses questionnaire. (c) Result of social presence questionnaire.

6. Discussion

6.1. RQ1: Does cheek pressure stimulation enhance virtual experience?

The experimental results revealed that cheek pressure stimulation improved presence and emotional responses compared to non-pressure stimulation, consistent with previous studies [WLT*20].

Regarding presence, both the single- and multi-point stimulation conditions yielded significantly higher scores in Experiment 1 (Figure 4a) and Experiment 2 (Figure 6a). Across all tasks in both experiments, pressure-involving conditions scored significantly higher on P1 and P3–P5 than the visual-only condition. For involvement, both stimulation conditions yielded higher P9 scores in all but Task 1-2, suggesting that pressure stimulation enhanced involvement and the attractiveness of the virtual world.

For realism, the results differed between experiments. In Experiment 1, significant differences on P11 and P12 were observed in two tasks, but not in Tasks 1–3, where some participants reported visuo-haptic incongruence. These results suggest that pressure feedback is effective for visible objects but less suitable for ambient stimuli. In Experiment 2, multi-point pressure produced lower P10 scores in Tasks 2-1 and 2-2, while pressure-involving conditions scored higher than the visual-only condition on P11 and P12. We attribute this discrepancy to the haptic sensation of the stimulator: P10 assessed holistic realism, whereas P11 and P12 focused on consistency with real-world experience. Accordingly, multi-point feedback reduced overall realism but was still perceived as plausible. Several participants also noted that the haptic sensation felt inconsistent with the agents’ hands, implying that the face’s high sensitivity and the expectation of soft touch made visuo-haptic incongruence more salient.

With respect to emotional responses, both pressure conditions significantly increased arousal, occasionally improved valence, and did not affect dominance. Arousal was consistently higher under pressure conditions, aligning with the prior reports [WLT*20]. For dominance, no differences were observed. This result is likely at-

tributable to the lack of interactivity in the scenarios, which limited participants’ sense of control and thus reduced dominance.

Valence results varied across tasks, consistent with the prior study [WLT*20]. In Experiment 1, single-point stimulation condition yielded significantly higher ER1 scores than the visual-only condition in Task 1-2, with participants noting that pressure feedback alleviated monotony and VR sickness. In Experiment 2, single-point stimulation improved Task 2-2 scores, and multi-point improved Task 2-3 scores. Participant comments provided further insight: in Task 2-2, haptic feedback increased comfort when the doctor avatar’s hand was partially occluded; in Task 2-3, most male participants reported comfort from dynamic pressure, while some female participants found repeated cheek touching unusual or unpleasant, reflecting cultural norms around facial contact. Overall, pressure feedback enhanced positive emotions via multiple mechanisms, including reducing cybersickness, improving comfort in occluded interactions, and leveraging spatial-temporal pressure variations, though social and cultural factors influenced its reception.

6.2. RQ2: Does cheek pressure stimulation improve social presence?

Experiment 2 results show that cheek pressure stimulation significantly improved social presence over the visual-only condition.

For co-presence, although the specific questions showing significant differences varied across tasks, pressure-involving conditions consistently outperformed the visual-only condition. In Task 2-1, SP3 scores were higher under single-point stimulation, likely due to pressure synchronized with the agent’s movements. In Task 2-2, single-point stimulation improved SP1–SP3, with participants noting greater awareness of the partner and stronger attention to the agent’s actions; without pressure, some felt as if they were merely watching a video. In Task 2-3, both stimulation conditions increased SP3–SP4, suggesting enhanced attempts to attract attention, though participants’ fondness for the Unity-chan avatar may also have contributed to higher SP4 scores.

With respect to allocational attention, significant differences were found across all tasks between visual-only and pressure conditions, indicating that pressure stimulation effectively attracted attention during participant-agent interactions.

As for PAU, SP6 scores were higher under both stimulation conditions in Tasks 2-2 and 2-3 but not in Task 2-1. The lack of difference in Task 2-1 appears to stem from participants' difficulty in interpreting the avatar's intention, whereas in the other tasks the social context was clearer.

With regard to PEI, SP8 scores were significantly higher under pressure conditions across all tasks. SP7 also showed significant differences in Tasks 2-1 and 2-3, but not in Task 2-2, likely because participants perceived the doctor avatar as simply examining their condition, making them less susceptible to the effects of pressure stimulation on moods influenced by the partner.

For PBI, significant differences were observed across all tasks for SP9-SP11 between the visual-only and both pressure conditions. These results suggest that pressure stimulation synchronized with the agents' actions enhanced behavioral interdependence.

6.3. RQ3: Does spatially-distributed cheek pressure stimulation offer a better experience than single-point stimulation?

There were few significant differences between the single- and multi-point pressure stimulation conditions for presence, emotional responses, and social presence. In several cases, differences appeared between the visual-only and single-point conditions, but not between the visual-only and multi-point conditions.

For presence, significant differences emerged only in P9 of Task 1-2 and P12 of Task 2-3, specifically between visual-only and single-point conditions. This may be related to the perception of force intensity under multi-point stimulation: more than half of the participants reported perceiving stronger force with multi-point than with single-point stimulation. Such illusory intensity was often judged inconsistent with visual cues, which disturbed the experience and reduced realism, resulting in lower P9 and P12 scores under multi-point conditions. In Experiment 2, P10 scores were significantly lower for multi-point than visual-only, and in Task 2-2 a difference was also found between single- and multi-point conditions, reinforcing the interpretation that illusory force intensity diminished realism and attractiveness.

For emotional responses, differences between single- and multi-point conditions were found only for valence. In Tasks 1-2 and 2-2, significant improvements occurred with single-point stimulation compared to visual-only condition, but not with multi-point stimulation, again reflecting illusory force effects. Interestingly, in Task 2-3, multi-point stimulation yielded higher valence than visual-only, while single-point showed no significant difference. Participants noted that the cheek-squishing interaction was enjoyable, with spatial and temporal variations in pressure described as comfortable, suggesting a context in which multi-point stimulation could positively affect valence.

For social presence, a significant difference appeared only in SP4 of Task 2-1, between visual-only and single-point conditions.

No significant differences were found for multi-point stimulation, again likely due to illusory force perception. Thus, distributed pressure stimulation had little impact on social presence.

7. Limitations

In our device, since the pressure stimulation units were fixed, the perception of pressure stimulation may vary across the participants. Nevertheless, our results perceived pressure stimulation on their cheeks and showed that cheek pressure stimulation effectively enhanced virtual experiences. As future work, we will incorporate precise facial geometry sensing systems.

Although we examined cheek pressure stimulation against visual feedback, we did not compare it with other modalities such as vibrotactile or with stimulation on other body parts such as the hands. In future work, we will investigate differences in user experience between facial pressure stimulation and vibrotactile, thermal, skin-drag, and hand pressure stimulation.

From participants' reports, we found that multi-point cheek pressure stimulation could induce an illusion of force intensity perception, rather than produce distinct pressure forces. We will further investigate what triggers this illusory phenomenon.

8. Conclusion

This paper explored the effect of spatially distributed facial pressure stimulation on virtual experiences, focusing on presence, emotional responses, and social presence. We developed a facial stimulation device with six servo-driven linear actuators mounted on an HMD and conducted two experiments under visual-only, single-point, and multi-point conditions. The first experiment assessed the impact of cheek pressure stimulation on presence and emotional responses when interacting with virtual entities (dog, leaves, rain), while the second examined its effect on presence, emotional responses, and social presence during interactions with virtual agents (human-like character, doctor avatar, attractive avatar).

The results revealed that cheek pressure stimulation significantly improved spatial presence and realism, particularly for visible objects. With respect to emotional responses, cheek pressure stimulation effectively enhanced arousal and, even under negative influences, provided pleasant experience. However, female participants were likely to have less positive impression when experiencing cheek-squishing by an avatar, due to unfamiliarity with such cheek contact. Regarding social presence, cheek pressure stimulation effectively enhanced co-presence, attractiveness of attention, understanding to the partner, emotional interdependence, and behavior interdependence. The results also suggest that spatial and temporal changes in stimulation intensity positively affected the perception to the partner, though effects appeared context-dependency. Overall, while spatially distributed stimulation showed limited advantages over single-point stimulation, dynamic spatially distributed feedback offered superior experiences in specific contexts.

Acknowledgment

This work is supported by JSPS KAKENHI Grant Number 24K20823.

References

- [AHJ*16] AHMED I., HARJUNEN V., JACUCCI G., HOGGAN E., RAVAJA N., SPAPE M. M.: Reach out and touch me: effects of four distinct haptic technologies on affective touch in virtual reality. In *Proceedings of the 18th ACM International Conference on Multimodal Interaction* (New York, NY, USA, 2016), ICMI '16, Association for Computing Machinery, p. 341–348. doi:10.1145/2993148.2993171. 2
- [ASJR*20] AL-SADA M., JIANG K., RANADE S., KALKATTAWI M., NAKAJIMA T.: Hapticsnakes: multi-haptic feedback wearable robots for immersive virtual reality. *virtual reality* 24 (2020), 191–209. 2
- [BFRS10] BICKMORE T. W., FERNANDO R., RING L., SCHULMAN D.: Empathic touch by relational agents. *IEEE Transactions on Affective Computing* 1, 1 (2010), 60–71. doi:10.1109/T-AFFC.2010.4. 2
- [BL94] BRADLEY M. M., LANG P. J.: Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry* 25, 1 (1994), 49–59. doi:https://doi.org/10.1016/0005-7916(94)90063-9. 5
- [BTPT19] BOUCAUD F., TAFIANI Q., PELACHAUD C., THOUVENIN I.: Social Touch in Human-agent Interactions in an Immersive Virtual Environment. In *Proceedings of the 14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications* (Prague, Czech Republic, Feb. 2019), pp. 129–136. doi:10.5220/0007397001290136. 2
- [BYB*07] BALENSON J. N., YEE N., BRAVE S., MERGET D., KOSLOW D.: Virtual interpersonal touch: Expressing and recognizing emotions through haptic devices. *Human-Computer Interaction* 22, 3 (2007), 325–353. 2
- [CCL*21] CHU S.-Y., CHENG Y.-T., LIN S. C., HUANG Y.-W., CHEN Y., CHEN M. Y.: Motionring: Creating illusory tactile motion around the head using 360° vibrotactile headbands. In *The 34th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2021), UIST '21, Association for Computing Machinery, p. 724–731. doi:10.1145/3472749.3474781. 2
- [CL22] COSTES A., LÉCUYER A.: The “kinesthetic hmd”: Inducing self-motion sensations in immersive virtual reality with head-based force feedback. *Frontiers in Virtual Reality* 3 (2022). doi:10.3389/frvir.2022.838720. 2
- [CTT*18] CHANG H.-Y., TSENG W.-J., TSAI C.-E., CHEN H.-Y., PEIRIS R. L., CHAN L.: Facepush: Introducing normal force on face with head-mounted displays. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2018), UIST '18, Association for Computing Machinery, p. 927–935. doi:10.1145/3242587.3242588. 2
- [FKTK20] FEICK M., KLEER N., TANG A., KRÜGER A.: The virtual reality questionnaire toolkit. In *Adjunct Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2020), UIST '20 Adjunct, Association for Computing Machinery, p. 68–69. doi:10.1145/3379350.3416188. 4
- [HB04] HARMS C., BIOCCHA F.: Internal consistency and reliability of the networked minds social presence measure. In *the 2004 Seventh Annual International Workshop: Presence* (2004), Alcaniz M., Rey B., (Eds.). URL: https://api.semanticscholar.org/CorpusID:201753502. 6
- [HNC09] HASHIMOTO Y., NAKATA S., KAJIMOTO H.: Novel tactile display for emotional tactile experience. In *Proceedings of the International Conference on Advances in Computer Entertainment Technology* (New York, NY, USA, 2009), ACE '09, Association for Computing Machinery, p. 124–131. doi:10.1145/1690388.1690410. 2
- [HOSK21] HOPPE M., OSKINA D., SCHMIDT A., KOSCH T.: Odin's helmet: A head-worn haptic feedback device to simulate g-forces on the human body in virtual reality. *Proceedings of the ACM on Human-Computer Interaction* 5, EICS (may 2021). doi:10.1145/3461734. 2
- [HRN*20] HOPPE M., ROSSMY B., NEUMANN D. P., STREUBER S., SCHMIDT A., MACHULLA T.-K.: A human touch: Social touch increases the perceived human-likeness of agents in virtual reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2020), CHI '20, Association for Computing Machinery, p. 1–11. doi:10.1145/3313831.3376719. 2
- [HSAA*23] HECQUARD J., SAINT-AUBERT J., ARGELAGUET F., PACCHIEROTTI C., LÉCUYER A., MACÉ M.: Fostering empathy in social virtual reality through physiologically based affective haptic feedback. In *2023 IEEE World Haptics Conference (WHC)* (2023), pp. 78–84. doi:10.1109/WHC56415.2023.10224380. 2
- [HSH*12] HOGGAN E., STEWART C., HAVERINEN L., JACUCCI G., LANTZ V.: Pressages: augmenting phone calls with non-verbal messages. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2012), UIST '12, Association for Computing Machinery, p. 555–562. doi:10.1145/2380116.2380185. 2
- [ISO*17] ICHINOSE A., SANO Y., OSUMI M., SUMITANI M., ICHIRO KUMAGAYA S., KUNIYOSHI Y.: Somatosensory feedback to the cheek during virtual visual feedback therapy enhances pain alleviation for phantom arms. *Neurorehabilitation and Neural Repair* 31, 8 (2017), 717–725. PMID: 28691602. doi:10.1177/1545968317718268. 2
- [JBA*24] JACUCCI G., BELLUCCI A., AHMED I., HARJUNEN V., SPAPE M., RAVAJA N.: Haptics in social interaction with agents and avatars in virtual reality: a systematic review. *Virtual Reality* 28, 170 (2024). doi:10.1007/s10055-024-01060-6. 1, 2
- [JKF*21] JINGU A., KAMIGAKI T., FUJIWARA M., MAKINO Y., SHINODA H.: Lipnotif: Use of lips as a non-contact tactile notification interface based on ultrasonic tactile presentation. In *The 34th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2021), UIST '21, Association for Computing Machinery, p. 13–23. doi:10.1145/3472749.3474732. 2
- [KC24] KIM H., CHOI S.: Expressing the social intent of touch initiator in virtual reality using multimodal haptics. In *2024 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (2024), pp. 416–425. doi:10.1109/ISMAR62088.2024.00056. 2
- [KKNK18] KAMEOKA T., KON Y., NAKAMURA T., KAJIMOTO H.: Haptopus: Transferring the touch sense of the hand to the face using suction mechanism embedded in hmd. In *Proceedings of the 2018 ACM Symposium on Spatial User Interaction* (New York, NY, USA, 2018), SUI '18, Association for Computing Machinery, p. 11–15. doi:10.1145/3267782.3267789. 2
- [KMW19] KROGMEIER C., MOUSAS C., WHITTINGHILL D.: Human-virtual character interaction: Toward understanding the influence of haptic feedback. *Computer Animation and Virtual Worlds* 30, 3-4 (2019), e1883. e1883 cav.1883. doi:https://doi.org/10.1002/cav.1883. 2
- [KRMS21] KAUL O. B., ROHS M., MOGALLE M., SIMON B.: Around-the-head tactile system for supporting micro navigation of people with visual impairments. *ACM Trans. Comput.-Hum. Interact.* 28, 4 (July 2021). doi:10.1145/3458021. 2
- [LSWL24] LAN R., SUN X., WANG Q., LIU B.: Ultrasonic mid-air haptics on the face: Effects of lateral modulation frequency and amplitude on users' responses. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2024), CHI '24, Association for Computing Machinery. doi:10.1145/3613904.3642417. 2
- [LYC*19] LIU S.-H., YU N.-H., CHAN L., PENG Y.-H., SUN W.-Z., CHEN M. Y.: Phantomlegs: Reducing virtual reality sickness using head-worn haptic devices. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2019), pp. 817–826. doi:10.1109/VR.2019.8798158. 2
- [LYM*20] LIU S.-H., YEN P.-C., MAO Y.-H., LIN Y.-H., CHANDRA

- E., CHEN M. Y.: Headblaster: A wearable approach to simulating motion perception using head-mounted air propulsion jets. *ACM Transactions on Graphics* 39, 4 (jul 2020). doi:10.1145/3386569.3392482. 2
- [NVS*22] NAKAMURA F., VERHULST A., SAKURADA K., FUKUOKA M., SUGIMOTO M.: Evaluation of spatial directional guidance using cheek haptic stimulation in a virtual environment. *Frontiers in Computer Science* 4 (2022). doi:10.3389/fcomp.2022.733844. 2
- [PBN12] PARK Y.-W., BAE S.-H., NAM T.-J.: How do couples use cheektouch over phone calls? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2012), CHI '12, Association for Computing Machinery, p. 763–766. doi:10.1145/2207676.2207786. 2
- [PLN10] PARK Y.-W., LIM C.-Y., NAM T.-J.: Cheektouch: An affective interaction technique while speaking on the mobile phone. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems* (New York, NY, USA, 2010), CHI EA '10, Association for Computing Machinery, p. 3241–3246. doi:10.1145/1753846.1753965. 2
- [PN13] PARK Y.-W., NAM T.-J.: Poke: a new way of sharing emotional touches during phone conversations. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (New York, NY, USA, 2013), CHI EA '13, Association for Computing Machinery, p. 2859–2860. doi:10.1145/2468356.2479548. 2
- [RJK*17] RANASINGHE N., JAIN P., KARWITA S., TOLLEY D., DO E. Y.-L.: Ambiotherm: Enhancing sense of presence in virtual reality by simulating real-world environmental conditions. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), CHI '17, Association for Computing Machinery, p. 1731–1742. doi:10.1145/3025453.3025723. 1, 2
- [RJTNT*18] RANASINGHE N., JAIN P., THI NGOC TRAM N., KOH K. C. R., TOLLEY D., KARWITA S., LIEN-YA L., LIANGKUN Y., SHAMALIAH K., EASON WAI TUNG C., YEN C. C., DO E. Y.-L.: Season traveller: Multisensory narration for enhancing the virtual reality experience. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2018), CHI '18, Association for Computing Machinery, p. 1–13. doi:10.1145/3173574.3174151. 2
- [Sal10] SALLNÄS E.-L.: Haptic feedback increases perceived social presence. In *Haptics: Generating and Perceiving Tangible Sensations* (Berlin, Heidelberg, 2010), Kappers A. M. L., van Erp J. B. F., Bergmann Tiest W. M., van der Helm F. C. T., (Eds.), Springer Berlin Heidelberg, pp. 178–185. 2
- [SPR*12] SAMANI H. A., PARSANI R., RODRIGUEZ L. T., SAADATIEN E., DISSANAYAKE K. H., CHEOK A. D.: Kissenger: design of a kiss transmission device. In *Proceedings of the Designing Interactive Systems Conference* (New York, NY, USA, 2012), DIS '12, Association for Computing Machinery, p. 48–57. doi:10.1145/2317956.2317965. 2
- [SRGS00] SALLNÄS E.-L., RASSMUS-GRÖHN K., SJÖSTRÖM C.: Supporting presence in collaborative environments by haptic force feedback. *ACM Trans. Comput.-Hum. Interact.* 7, 4 (Dec. 2000), 461–476. doi:10.1145/365058.365086. 2
- [SSH22] SHEN V., SHULTZ C., HARRISON C.: Mouth haptics in vr using a headset ultrasound phased array. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2022), CHI '22, Association for Computing Machinery. doi:10.1145/3491102.3501960. 1, 2
- [SU17] SATO Y., UEOKA R.: Investigating haptic perception of and physiological responses to air vortex rings on a user's cheek. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), CHI '17, Association for Computing Machinery, p. 3083–3094. doi:10.1145/3025453.3025501. 2
- [TCL*22] TSENG C.-M., CHEN P.-Y., LIN S. C., WANG Y.-W., LIN Y.-H., KUO M.-A., YU N.-H., CHEN M. Y.: Headwind: Enhancing teleportation experience in vr by simulating air drag during rapid motion. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2022), CHI '22, Association for Computing Machinery. doi:10.1145/3491102.3501890. 2
- [TLY*24] TRAN T. Q., LANGLLOTZ T., YOUNG J., SCHUBERT T. W., REGENBRECHT H.: Classifying presence scores: Insights and analysis from two decades of the igroup presence questionnaire (ipq). *ACM Trans. Comput.-Hum. Interact.* 31, 5 (Nov. 2024). doi:10.1145/3689046. 5
- [TNS*20] TEO T., NAKAMURA F., SUGIMOTO M., VERHULST A., LEE G. A., BILLINGHURST M., ADCOCK M.: WeightSync: Proprioceptive and Haptic Stimulation for Virtual Physical Perception. In *ICAT-EGVE 2020 - International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments* (2020), Argelaguet F., McMahan R., Sugimoto M., (Eds.), The Eurographics Association. doi:10.2312/egve.20201253. 2
- [WGL*19] WANG D., GUO Y., LIU S., ZHANG Y., XU W., XIAO J.: Haptic display for virtual reality: progress and challenges. *Virtual Reality & Intelligent Hardware* 1, 2 (2019), 136–162. Haptic Interaction. doi:https://doi.org/10.3724/SP.J.2096-5796.2019.0008. 1
- [WHH*19] WANG C., HUANG D.-Y., HSU S.-w., HOU C.-E., CHIU Y.-L., CHANG R.-C., LO J.-Y., CHEN B.-Y.: Masque: Exploring lateral skin stretch feedback on the face with head-mounted displays. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2019), UIST '19, Association for Computing Machinery, p. 439–451. doi:10.1145/3332165.3347898. 2
- [WLT*20] WILBERZ A., LESCHTSCHOW D., TREPkowski C., MAIERO J., KRUIFF E., RIECKE B.: Facehaptics: Robot arm based versatile facial haptics for immersive environments. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2020), CHI '20, Association for Computing Machinery, p. 1–14. doi:10.1145/3313831.3376481. 1, 2, 4, 7
- [WNS*22] WATANABE K., NAKAMURA F., SAKURADA K., TEO T., SUGIMOTO M.: An Integrated Ducted Fan-Based Multi-Directional Force Feedback with a Head Mounted Display. In *ICAT-EGVE 2022 - International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments* (2022), Uchiyama H., Normand J.-M., (Eds.), The Eurographics Association. doi:10.2312/egve.20221276. 2
- [WRHR19] WOLF D., RIETZLER M., HNATEK L., RUKZIO E.: Face/on: Multi-modal haptic feedback for head-mounted displays in virtual reality. *IEEE Transactions on Visualization and Computer Graphics* 25, 11 (2019), 3169–3177. doi:10.1109/TVCG.2019.2932215. 1, 2
- [WYL21] WEE C., YAP K. M., LIM W. N.: Haptic interfaces for virtual reality: Challenges and research directions. *IEEE Access* 9 (2021), 112145–112162. doi:10.1109/ACCESS.2021.3103598. 1
- [YML*23] YU N.-H., MA S.-Y., LIN C.-M., FAN C.-A., TAGLIALATELA L. E., HUANG T.-Y., YU C., CHENG Y.-T., LIAO Y.-C., CHEN M. Y.: Drivingvibe: Enhancing vr driving experience using inertia-based vibrotactile feedback around the head. *Proc. ACM Hum.-Comput. Interact.* 7, MHCI (Sept. 2023). URL: https://doi.org/10.1145/3604253, doi:10.1145/3604253. 2