Exploring Pseudo Hand-Eye Interaction on the Head-Mounted Display

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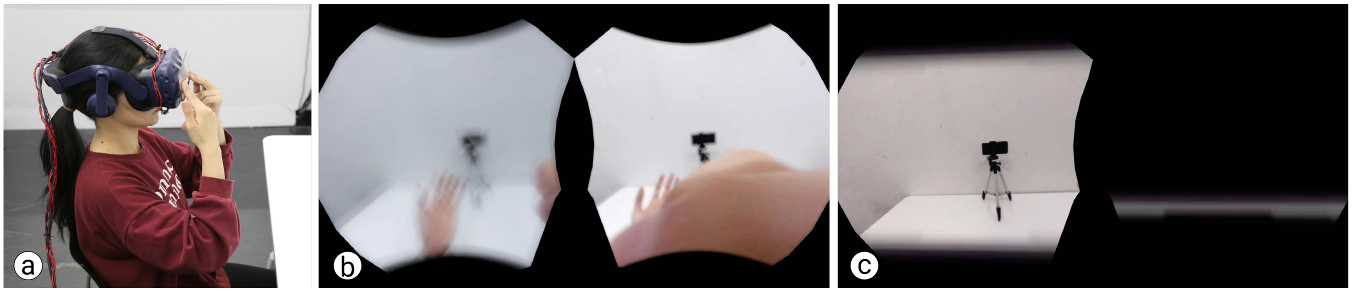

Figure 1: Interacting with the proof-of-concept prototype (a) to experience rubbing the eyes to clear up blurry vision (b) or closing eyelids in response to touch (c).

ABSTRACT

Virtual and augmented reality devices and applications have enabled the user to experience a variety of simulated real-life experiences through first-person visual, auditory, and haptic feedback. However, among the numerous everyday interactions that have been emulated, the familiar interaction of touching or rubbing the eyes is yet to be explored and remains to be understood. In this paper, we aim to understand the components of natural hand-eye interaction, propose an interaction technique through a proof-of-concept prototype head-mounted display, and evaluate the user experience of the prototype through a user study. In addition, we share insights emerged from the studies with suggestions for further development of interaction techniques based on combinations of hardware and software.

CCS CONCEPTS

• **Human-centered computing → Gestural input**; *Mixed / augmented reality*; Touch screens.

KEYWORDS

head-mounted display, interaction technique, touch input, visual effects, first-person view, pseudo hand-eye interaction

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1 INTRODUCTION

In 2015, the affordable consumer-grade head-mounted displays (HMD) market grew explosively as products such as Samsung GearVR, Google Cardboard, HTC VIVE, made virtual reality (VR) accessible to the average consumer, beginning the third wave of VR [7]. With the HMD device market growth, increasingly lighter devices with higher display resolutions continued to develop. Following this trend was the vast development of first-person view (FPV) content to be consumed using the new HMD technology. Naturally, the goal of content developers was to provide more rich, immersive first-person user experiences during content consumption.

To enrich the FPV experience, there have been continuous attempts in academia and in industry to create holistic immersive experiences for the users, integrating various modalities including not only visual, but also auditory, tactile, and kinesthetic feedback. These applications allow users to realistically experience emulated content that is comparable with real-life experiences, such as walking, touching, or other interactions with virtual or augmented environments. One familiar action we perform regularly and without much thought that is yet to be implemented in virtual and augmented environments is the common interaction of *touching or rubbing one's own eyes.*

The goal of this exploratory research project is to study and understand the experience of first-person interaction of touching the eyes and to verify the feasibility of enriching the FPV experience through enabling hand-eye interaction during the use of a

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head-mounted display. Through the development and evaluation of a proof-of-concept prototype, user observation, and post-hoc interviews, we aim to gain understanding of factors to consider when developing a software-hardware interface enabling first-person pseudo hand-eye interaction and to offer suggestions for developing an improved interface along with suggested appropriate scenarios.

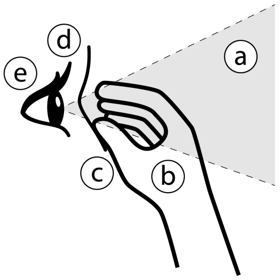

Figure 2: Five key hand-eye interaction components were identified to be implemented in the proof-of-concept prototype. These include the visual stream of information of the surroundings (a), a representation of the hand (b), a tactile sense of when the hand makes contact with the eyes (c), the eyelids covering the eye (d), and the optical aberrations that occur as a result of hand-eye contact (e).

2 TOUCHING AND RUBBING EYES: INTERACTION CONCEPT

We propose an approach to resemble the physical experience of touching the eyes with one hand, but without involving direct physical contact. We named this concept *pseudo hand-eye* interaction, and it consists of delivering the visual response of virtual eyelids and optical effects that result from the hand making contact with not the eyes but the HMD itself. By creating such virtual representation of the skin covering the eye and the visual changes that happen in response to the touch of the hand on the HMD, an interaction is formed, mimicking natural hand-eye interaction with potential to enrich the first-person experience.

In order to implement pseudo hand-eye interaction, we first decomposed the first-person hand-eye interaction into five main components (fig. 2). The first component is the eye that functions as the window through which our body perceives a constant stream of visual feedback from our surroundings. The second is the hand which is visible to our eyes when it enter our line of sight and can occlude our vision in varying degrees depending on its distance in front of the iris. The third are the eyelids which cover the eyes, blink reflexively in response to the touch of the hands, and occlude completely our vision when closed. The fourth is the tactile perception of the eye and the skin around the eyes that gives us feedback about when the eye has made contact with the hand. The fifth are the visual changes that occur as a result of interacting with the eyes with the hands, such as temporary loss of focus or optical defocus. We implemented each of these five components of first-person hand-eye interaction into a simplified proof-of-concept prototype to use to explore the pseudo hand-eye interaction space. In this paper we did not address the tactile feedback or haptics on/around the eyes as an interaction factor as our goal was to explore if simulating natural hand-eye interaction without direct touch between the hands and the eyes was a feasible approach. Thus, we focused on implementing the visual interaction elements in response to touch inputs on the HMD.

3 IMPLEMENTATION

We considered how to implement each interaction component described in the previous section. For the visual feedback stream to be viewed by the eye, an external camera near the user's eyes that captures the surroundings can be used. For the visual of the hands, using the external camera for the eyes automatically enables the user to see their own hands. For the eyelids, a black plane can be implemented inside the virtual reality environment (VRE) in front of the virtual camera location so that each can act as virtual eyelids that can move to close off or open up the user's field of view (FOV). For the visual changes, a virtual transparent window can be implemented in the VRE immediately behind the eyelids of each eye to act as a visual filter through which the eye can see its surroundings with desired visual effects.

3.1 Hardware

We selected a VIVE Pro[1] head-mounted display, because it has two external pass-through cameras, each positioned on the front of the HMD roughly corresponding to the eye positions, and therefore enabling stereoscopic vision. For touch input, to enable individuality of touch sensing between the eyes, we utilized two transparent 4.3 inch capacitive touch panels (LCT-GG043061C)[2], one over each stereoscopic camera (fig. 3). To read the touch input data, we interfaced each capacitive touch panel with an Arduino Mega board[3] for serial communication through COM ports on the PC to the Unity environment using the Ardity Unity Package[4].

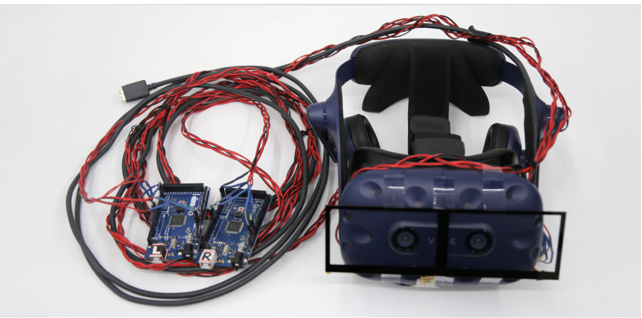

Figure 3: The modified prototype was composed of two capacitive touch panels attached to the VIVE Pro HMD. Each touch panel was interfaced with an Arduino Mega to communicate with the software via serial connection.

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[1] https://www.vive.com/eu/product/vive-pro/
[2] https://www.devicemart.co.kr/goods/view?no=12733829
[3] https://store.arduino.cc/usa/mega-2560-r3
[4] https://ardity.dwilches.com/

3.2 Software Environment

Unity was used for creating the FPV environment with the HTC VIVE's SRWorks SDK[5] to enable using the pass-through camera feed. For implementing virtual eyelids, a pair of black-colored planes were placed in front of the eyes, each representing the top and bottom eyelids. The animator component was applied to the eyelids and were set to have two states - the default open state and the closed state.

For the optical effects, we made the decision to implement a highly common type of optical aberration, the optical defocus [1] or more commonly known as blurring of vision. Aside from optical defocus caused by ocular conditions such as myopia (nearsightedness), hyperopia (far-sightedness), and regular astigmatism [24], temporary blurring of vision can be caused by watery eyes, rheum formation in the eyes, or even from rubbing the eyes with slight pressure. As visual blurring is a widely relatable experience of optical aberration for healthy vision, we chose to implement the optical defocus effect to be used in the proof-of-concept prototype using the UI Blur asset [6] that uses a custom shader to blur everything seen through a GameObject. Using this asset, we placed a transparent screen of varying blurriness in front of the virtual eyelids to simulate the optical defocus effect. Figure 4 shows the integration of hardware and software components of the system.

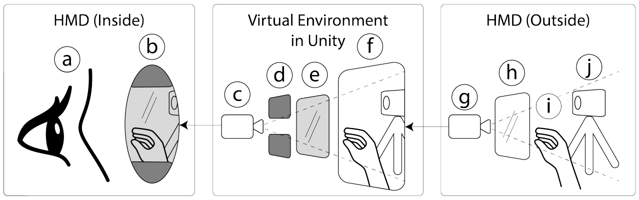

Figure 4: System diagram of prototype. The user's eye (a) sees through the circular display inside the HMD (b). On the display is shown a view of the virtual environment through the virtual camera (c), with virtual eyelids (d) and a transparent blur filter (e) positioned in front of the virtual camera. The pass-through view of the surrounding environment (f) is seen through the built-in pass-through camera on the outside of the HMD (g). A transparent capacitive touch panel (h) senses the touch of the user's hand (i). A camera facing the user on a tripod (j) records the user's interactions.

4 USER STUDY

The user study was conducted with the goals to understand natural hand-eye interaction, evaluate the HMD prototype for pseudo hand-eye interaction, and collect suggestions for improving the prototype interaction. Consequently, the study consisted of three sessions: The first session involved a demographics questionnaire and participant demonstration in conjunction with a semi-structured interview. The second session involved evaluating the proof-of-concept HMD prototype for pseudo hand-eye interaction with four different visual effect conditions. The third session involved a semi-structured interview on points for improvement as well as suggestions for future applications. All the interview data was later transcribed into text format for line-by-line Open Coding. Twelve Design major students were recruited for the main study (five females) aged 22-29 years old (M = 23.83, SD = 2.44). The study duration lasted approximately 50 minutes each, and participants were compensated with 9 USD in local currency.

4.1 Demographics & Participant Demonstration

Participants filled out a questionnaire with demographic information , and indicated familiarity with HMDs and Augmented Reality, duration of usage of vision-correction devices if applicable, and their dominant hand. Afterwards they were asked to fill out contextual questions related to their everyday natural hand-eye interactions including the frequency of touching/rubbing their eyes on a regular basis, the cues or causes for those interactions, and ranking the causes in order of frequency of occurrence. Participants were then asked to demonstrate their self-reported top three most frequent but non-overlapping hand-eye interactions they had listed, while using the think aloud protocol.

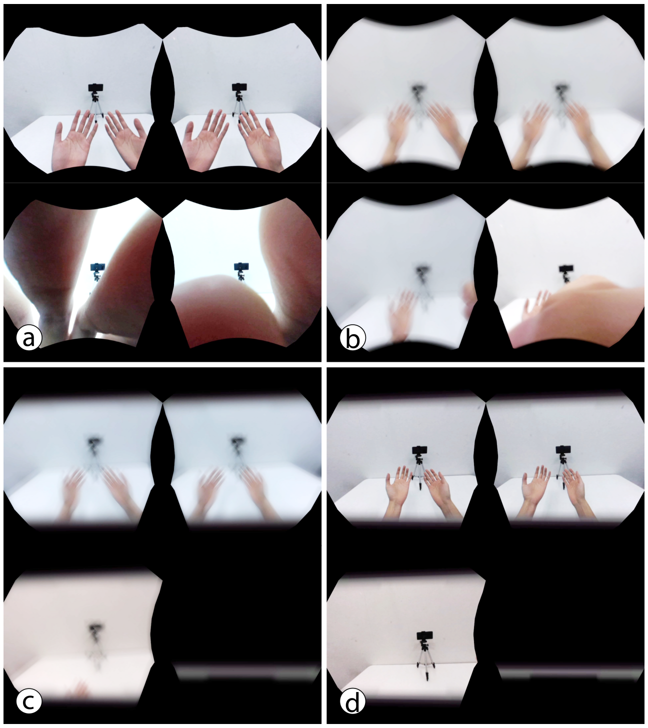

Figure 5: The four visual response conditions experienced by participants: Control (a), only blur (b), both blur & eyelids (c), and only eyelids (d). For each condition, the top image shows the default state and the bottom image represents the visual effect achieved when touching or rubbing the prototype.

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[5] https://developer.vive.com/resources/vive-sense/sdk/vive-srworks-sdk/0930/srworks-xr-sdk-unity-plugin/

[6] https://assetstore.unity.com/packages/vfx/shaders/ui-blur-173331

4.2 Evaluation with Interactive Prototype

4.2.1 Experimental Conditions. The independent variable of the study was the visual changes (i.e. blinking or blurring) representing the reaction of the eyes in response to user touch interactions. The dependent variables were participant ratings of realism, presence, and enjoyment about each condition experienced. For the control condition, no additional visual effects were presented aside from the pass-through camera feed (fig. 5a). For the eyelid (E) condition, when participant hands came in contact with the panels on the front of the HMD, the virtual eyelids closed (fig. 5d). For the blurriness (B) condition, participant vision would appear blurry, and rubbing the touch panels gradually made the vision clearer (fig. 5b). For the condition with both eyelid and blurriness effects (E+B), both effects were presented together (fig. 5c). The control condition was always shown first, and the remaining three visual effects were presented in balanced order.

4.2.2 Evaluating Presented Conditions. Participants were asked to wear the proof-of-concept HMD prototype and interact with it as if it was part of their own body, performing each of the three interactions identically as they had demonstrated in the first session. Upon wearing the HMD, the participants were able to see their immediate surroundings and their own hands (see figure 5a). Before experiencing each condition, participants were shown a black screen and were told which condition they would be experiencing with what type of interaction to expect.

Similar to prior work [8, 19], after each condition participants were asked to rate each experience on three common criteria for evaluating interactions using the HMD - Realism, Presence, and Enjoyment - each on a 7-point Likert scale. To avoid confusion of evaluation terms among participants, each participant was given the definition of each evaluation term used in the study, prior to evaluation. For Realism, they were asked to compare their interaction experience with the HMD prototype with their experience during the interaction demonstration in the first session and to consider how realistic and similar the experience was. For Presence, participants were asked to consider how much they felt being actually present in the environment shown to them compared to feeling like seeing looking at a display placed in front of their eyes. For Enjoyment, they were asked to consider the overall enjoyment of experiencing the interaction in the given condition.

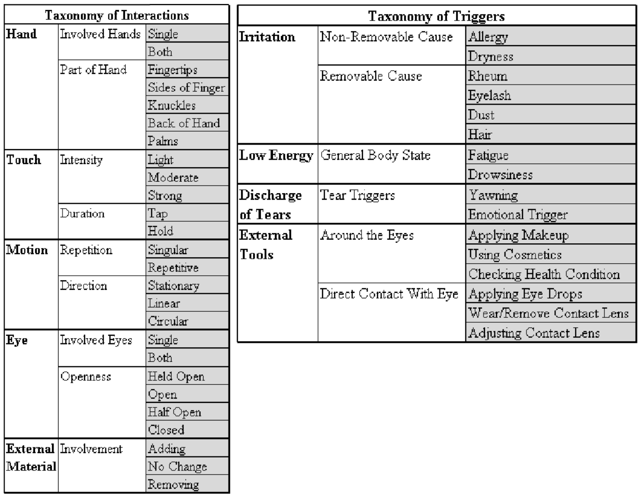
4.3 Collecting Prototype Feedback & Application Suggestions

After evaluation, a follow-up interview was conducted to understand what factors played a role in deciding the scores that were given. Participants were first interviewed about their experience with the prototype and the visual effects, specifically about points of the interaction that were awkward or strange. Afterwards, they were asked to share thoughts or ideas on how to improve the hardware of the prototype to make it more enjoyable, natural, or realistic and were given a drawing template form to visually express their ideas. Lastly, participants were asked in what fields, scenarios, or situations would such device enabling pseudo hand-eye interaction be useful, enjoyable, or necessary for application.

5 RESULTS

5.1 Natural Hand-Eye Interaction

According to participant responses, the top three most frequent hand-eye interactions varied between each participant and included not only triggers such as eye irritation, eye fatigue, removing dirt, and yawning, but also wearing/removing contact lenses, adding tears to dry eyes, applying lotion, and checking own health status. As expected, even when demonstrating performing an action in response to the same trigger, there were differences between participants in how the gestures were executed. Based on the observations and participant response, preliminary taxonomies of hand-eye interactions and their triggers (fig. 6) have been formulated following previous work [25].



Taxonomy of Interactions		
Hand	Involved Hands	Single
		Both
	Part of Hand	Fingertips
		Sides of Finger
		Knuckles
		Back of Hand
		Palms
Touch	Intensity	Light
		Moderate
		Strong
	Duration	Tap
		Hold
Motion	Repetition	Singular
		Repetitive
	Direction	Stationary
		Linear
		Circular
Eye	Involved Eyes	Single
		Both
	Openness	Held Open
		Open
		Half Open
		Closed
External Material	Involvement	Adding
		No Change
		Removing

Taxonomy of Triggers		
Irritation	Non-Removable Cause	Allergy
		Dryness
	Removable Cause	Rheum
		Eyelash
		Dust
		Hair
Low Energy	General Body State	Fatigue
		Drowsiness
Discharge of Tears	Tear Triggers	Yawning
		Emotional Trigger
External Tools	Around the Eyes	Applying Makeup
		Using Cosmetics
		Checking Health Condition
	Direct Contact With Eye	Applying Eye Drops
		Wear/Remove Contact Lens
		Adjusting Contact Lens

Figure 6: Preliminary taxonomies of hand-eye interactions (left) and triggers (right) based on participant response and demonstration.

5.1.1 Trigger Factors. The factors that cause or elicit the interactions were identified as categorized as "trigger factors".

The Irritation trigger is either non-removable or removable depending on whether it can be alleviated through physically removing something from the eye.

For Low Energy triggers, the cause is not directly in the eyes, but is by the overall condition of the body. Consequently, the actions in response to this type of trigger are therapeutic in nature, such as massaging the eyes or applying pressure on them.

The Discharge of Tears trigger is caused by yawning or emotional cues but did not cause irritation, making it a separate category.

For External Tools triggers, the cause was due to the intentional use of a tool either on the skin around the eyes such as for makeup or used in direct contact with the eyes, such as applying eye drops or using contact lenses.

5.1.2 Interaction Factors. The factors that describe the type of hand-eye interaction observed were identified and categorized as "interaction factors".

Figure 7: Three most frequent hand-eye interactions for each participant.

For the Hand factor, participants were seen to use various parts of their hands and involve different number of hands depending on the specificity, precision, and complexity of the actions.

For the Touch factor, different touch intensities and duration were observed depending on how delicate the action is and how successful the participant is at alleviating the trigger .

For the Motion factor, different hand motion direction and repetition were observed depending on how successfully the trigger is alleviated or whether the action was for therapeutic purposes.

For the Eye factor, different number of eyes and amount of eye-openness were observed for different triggers depending on the purpose of the action, tendencies of the participants, and the involvement of the eyes.

For the External Material factor, interactions could be categorized into adding, removing, or not changing the material in or on the eyes.

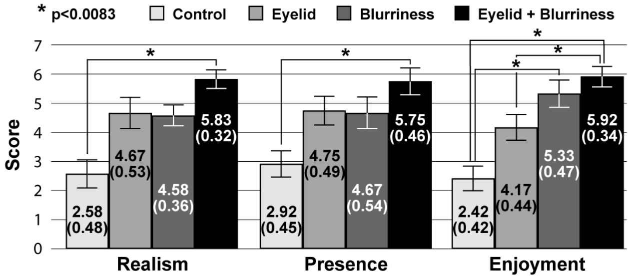


Figure 8: Plots of average scores of each condition per evaluation factor with standard error bars.

5.2 Prototype Evaluation

5.2.1 Quantitative Results. Evaluation scores on realism, presence, and enjoyment factors in each of the 4 experimental conditions from the 12 participants are shown in Figure 8. Friedman tests were performed for each of the factors. Results indicated that there was a statistically significant difference in perceived realism($\chi^2(2)$ = 15.316, p = 0.002), presence($\chi^2(2)$ = 18.520, $p < 0.001$), and enjoyment ($\chi^2(2)$ = 26.832, $p < 0.001$) depending on which type of visual effect was experienced while using the prototype. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.0083$.

For *realism*, there was a statistically significant difference in perceived realism between control vs Eyelids+Blurriness trials (Z = -2.954, p = 0.003). For *presence*, there was a statistically significant difference in perceived presence between control vs Eyelids+Blurriness trials (Z = -2.949, p = 0.003). For *enjoyment*, there was a statistically significant difference in perceived enjoyment between control vs Blurriness trials (Z = -2.944, p = 0.003), control vs Eyelids+Blurriness trials (Z = -3.071, p = 0.002), and Eyelids vs Eyelids+Blurriness trials (Z = -2.994, p = 0.003).

5.2.2 Qualitative Results and suggestions. Key differences were observed from the second session involving offsets in placement of the fingers/hand on the prototype compared to natural hand-eye interaction. In one example of the "wearing contact lens" interaction, P4 was not aware of the position of one hand on the eye in relation to the other, showing offsets in finger placement of both hands that would be considered unnatural in a setting without the prototype.

Many participants (P1, P3, P4, P6, P8, P11) verbally expressed their surprise, fascination, and enjoyment through interjections as "wow", "oh", and "fascinating". Some comments appeared repeatedly as participants were thinking-aloud, one such comment being about the appropriateness of the closing of the eyelids. As mentioned in the results section, even for the same trigger, participants responded with varying interactions factors, depending on their preferences. As a result, participants (P1, P2, P3, P5, P6, P9, P11, P12) mentioned the unnaturalness and non-appropriateness of the eyelids closing completely in response to the touch of the hand for held open, open, or half open interactions such as removing rheum or eyelash, applying makeup, eyedrops, or wearing contact lenses. Some participants (P3, P6, P8, P12) mentioned from the beginning that rubbing against a hard surface was awkward and unnatural.

5.3 Prototype Feedback & Suggestions

5.3.1 Feedback on Visual Effects. P1 and P3 identically mentioned that the interaction of rubbing to make vision become more blurry is a more natural interaction when considering the device as the eye. The implemented effect in the prototype (blurred to clear) is more appropriate if the prototype was considered as glasses/goggles or an external device separate from the body. Also, depending on what visual effects they experienced, P3, P4, P6 mentioned different mental models of the prototype can be considered. This was apparently a response to the conditions without the eyelid as the eyelids would

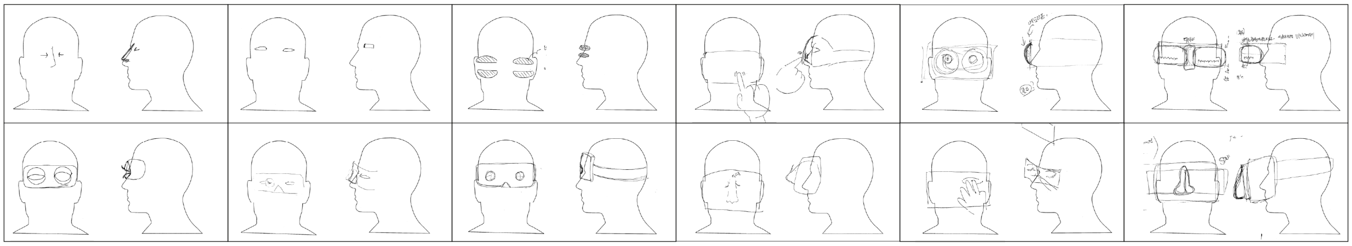


Figure 9: Visuals by participants communicating form factor suggestions to improve prototype.

normally not react to when the finger is placed over glasses or goggles.

5.3.2 Feedback on Hardware. Most participants (P1, P2, P3, P4, P5, P6, P7, P10, P11, P12) mentioned the need for physical features that act as reference points when interacting with the eyes. According to comments(P1, P2, P3, P5, P8, P11), the nose serves as an important reference point for not only diving the touchable surface into left and right individual surfaces, but it also serves as a physical limit against users can push or press to perform natural interactions. For interactions such as putting on contact lenses, P4 suggested adding points of reference for the eyelids for more precise control when opening the eyes gradually or keeping them open. Because the proof-of-concept prototype was implemented using flat capacitive touch panels as the input surface, soft, warm, and flexible materials were suggested (P4, P6, P8, P11) to be implemented to represent the parts of the eye to be touched, which would be more effective in making a more believable extension of the body, instead of a device.

5.3.3 Suggested Applications. Some application suggestions were about simulating daily-life interactions in the VR environment, such as fainting and waking up (P2), waking up with blurry vision that can be cleared when rubbed (P4, P8, P11), or wearing contact lens (P7), etc. Other participants suggested ideas for reacting to the environment such as closing or covering the eyes in response to bright light or moving from a dark to bright environment (P1, P3) or squinting against the wind on a high speed motorcycle (P11), fogging vision in response to tear gas that is rubbed to clear it (P2), or clearing the FOV from mud, blood, or blizzard (P4). Also, some application suggestions were about representing the condition of the body in FPV in game environments, such as sleepiness (P6) or fatigue (P8), where eyelids fall or vision becomes fuzzy (P12), or the blurring of vision after being punched in the face which can be cleared when the eyes are rubbed (P3).

6 DISCUSSION

Through our study, we aimed to understand: (1) The triggers and the corresponding execution of natural hand-eye interactions, (2) the feasibility of pseudo hand-eye interaction through a proof-of-concept prototype HMD, and (3) points for improving pseudo hand-eye interaction and potential applications of the approach.

(1) Natural Hand-Eye Interaction: We identified various hand-eye interaction factors and triggers that included but were not limited to those identified by previous work in the medical field [16, 17]. Replicating these triggers for experiencing while wearing a HMD requires considerations for simulating visual or tactile aspects. In this paper, visible components of eyelid movement or blurry vision have been implemented, but for simulating invisible triggers such as dryness or allergy, a tactile or some other creative alternate approach would be necessary for realistic interaction.

(2) Pseudo Hand-Eye Interaction Feasibility & Prototype Evaluation: The minimal proof-of-concept prototype demonstrated its effectiveness in enhancing the realism, presence, and enjoyment of pseudo hand-eye interaction, despite its lack of tactile feedback. However, as participants (P2, P3, P5) mentioned, implementing tactile sensations, similarly to previous work [4, 22], is expected to enhance the embodiment of the device and resulting realism. Further leveraging on the tactile feedback, the physical interaction with the skin on/around the eyes can be used not only as feedback mapped to the user's touch, but also be utilized as a physical trigger for a pseudo hand-eye interaction, such as mild eye irritation or heavy eyelids. Designing the haptic feedback to serve as both a benign irritant and the source of relief can be an interesting approach worth exploration.

(3) Improving Interaction & Potential Applications: We evaluated the effectiveness of simulating the response of the human eye to the touch of the hands on the HMD through pseudo hand-eye interaction. During the study, we received suggestions (P6, P10) on enhancing the interaction through implementing non eye-related or non-realistic visual effects. Such suggestions include enhancing the perception of refreshment when clearing blurry vision through exaggerated sharpness, increase in brightness, or particle effects commonly used in cartoon visualization. Another suggested approach was to visualize the removable irritation triggers (e.g. rheum, eyelash, dirt, etc.) on the user's hand after successful removal to deliver a sense of satisfaction. This is worth noting as for cases such as the proof-of-concept prototype that lack tactile feedback, satisfaction from an interaction can be elicited only visually, so considering presenting the user the direct results of their efforts even after the completion of an interaction can be effective as well.

6.1 Limitations

Limitations of the detail of interaction design were apparent from user study. In the proof-of-concept prototype presented, interactions were highly simplified and did not offer a high level of granular control to the participant. Nevertheless, through the study it was shown that in specific cases, the visual effects were indeed appropriate, and that further development of detail would allow the implementation of more appropriate interactions.

Because in the second session the eyelid and blurriness effects were shown equally for all participant interactions, there were definite times when one interaction was more appropriate over another. For example, when putting on contact lenses, because the eyes are intentionally held open, the interaction of closing eyelids in response to the user's touch was not an appropriate response. However, the participant evaluation of realism, presence, and enjoyment were about the overall experience of the visual condition, regardless of interaction appropriateness, and is therefore difficult to say which visual effect precisely had a stronger effect over the other. Additionally, as the preliminary taxonomies presented were based on 36 interactions from 12 study participants, further study specifically focusing on the interaction with the involvement of more users would help to develop an extensive taxonomy.

6.2 Future Work

The interaction taxonomy can be improved through future studies with more participants while considering a variety of different factors of possible interactions. Based on the taxonomy, designing detailed interactions and an improved hardware form factor with additional input and output modalities or more granular and responsive control of visuals. The technique proposed in this paper also has potential to be explored in terms of different functional purposes and alternate research goals. Instead of implementing realistic visual effects that represent human vision through virtual eyelid movement or ocular condition simulation, one alternate approach would be implementing non-realistic visual effects that represent super-human visual capabilities. Our technique can also be used to visualize wavelengths that are beyond the visible spectrum of electromagnetic waves for human eyes, such as infrared or ultraviolet vision. Such technique could then be used to educate about invisible electromagnetic waves, and about how they interact with our eyes and our surroundings under prolonged exposures.

7 RELATED WORK

7.1 Human Vision Simulation

Using the FPV view of HMDs in conjunction with eye-tracking techniques, researchers have attempted to create visual impairment representations in medical applications more precisely through gaze-contingency. Using eye-tracking, common gaze-contingent visual impairments have been presented in AR/VR to better understand visual impairments [9] [11], to understand street-crossing behavior of macular degeneration patients at a roundabout [26], to help quantify key everyday difficulties for visual impairment patients [10], and to test asymmetric peripheral vision loss [3].

7.2 Touch Interaction on the Face

In the Human-Computer-Interaction domain, interactions with various parts of the face using the hands and social acceptability have been explored. Serrano et al. [20] explored hand-to-face interactions to find techniques suitable for mobile tasks and examined the social acceptability, and Lee et al. [12] explored strategies for developing socially acceptable hand-to-face input actions. Oh and Findlater [18] explored on-body interaction for users with visual impairments on the hands, forearm, neck, and face area as a feasible input space for mobile devices and applications. Other works focused on enabling specific facial features as input interaction space. CheekInput [27] assessed touch input on the cheeks as an input modality, and Masai et al. [15] presented a smart eyewear prototype that can detect rubbing gestures on the face independent from facial expressions. Using advanced computer vision techniques, InterFace. [14] used hand-over-face (HOF) gestures with the face as a touch surface to interact with smartphones. Itchy Nose [13] senses finger movements on the nose through a glasses prototype to enable discreet gesture interactions.

7.3 Hand Interaction on the HMD

Additionally, there works in the field of HCI about using the HMD as a platform on which interactions with the hand are enabled. ExtensionClip [21] enables back-of-device touch interaction on a cardboard HMD using a pair of magnets and capacitive coupling. FaceWidgets [23] explored tangible input interactions on the front of an HMD via various widget modules. Enabling touch input interaction through using touch panels also have been explored. FaceTouch [5] assessed touch input on the front of the HMD as a reliable input modality. FrontFace [2] uses eye-tracking and a front-facing screen on an HMD that can be touched to enable communication between HMD user and outsiders. Similarly, FaceDisplay [6] explored asymmetric multi-user interaction between a VR HMD user and a non-HMD user.

8 CONCLUSION

In this exploratory paper, we proposed the concept of pseudo hand-eye interaction as a novel interaction technique for enriching the first-person view experience while using an HMD. We described the development and implementation of a proof-of-concept HMD prototype with touch-sensing capability enabled through capacitive touch panels placed over each pass-through camera that represents each eye. The software component involved the implementation of two distinct factors of hand-eye interaction - the movement of virtual eyelids in response to the touch of the hand and the change in clarity of vision as a response to the hand touching the eyes. Through user study sessions, we gained understanding of natural hand-eye interaction, evaluated the prototype's effect on realism, presence, and enjoyment, and received user feedback on the visual and hardware components of the prototype along with potential application scenarios. The results showed distinct patterns of natural hand-eye interaction which transferred when performing the same interactions while wearing the HMD prototype, the effectiveness and appropriateness of the visual effects in enriching the first-person experience for given actions and situations, and key improvement points in the fidelity of the visual effect and hardware form factor with various suggestions for applying the interaction technique in different scenarios.

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