Visceral Interfaces for Privacy Awareness of Eye Tracking in VR

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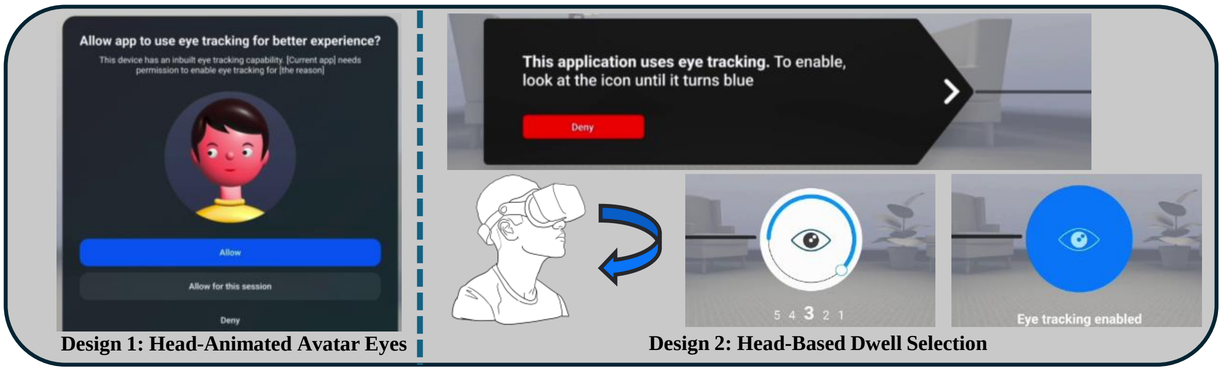

Figure 1: We designed and evaluated visceral interfaces to increase privacy awareness of VR eye tracking, including a permissions request scenario. Pictured are two visceral designs: Design 1 taps into visceral cues of avatar eyes animated based on head movements and Design 2 uses friction of required head movement and dwell on an icon to delay the user while they consider their choice. Design 2 also uses head data as a proxy for actual gaze data to relay the accuracy and responsiveness of VR eye tracking.

Abstract

Eye tracking is increasingly being integrated into virtual reality (VR) devices to support a wide range of applications. It is used as a method of interaction, to support performance optimizations, and to create adaptive training or narrative experiences. However, providing access to eye-tracking data also introduces the ability to monitor user activity, detect and classify a user's biometric identity, or otherwise reveal sensitive information such as medical conditions. As this technology continues to evolve, users should be made aware of the amount of information they are sharing about themselves to developers and how it can be used. While traditional terms of service may relay this type of information, previous work indicates they are not accessibly conveying privacy-related information to users. Considering this problem, we suggest the application of visceral interfaces that are designed to inform users about eye-tracking data within the VR experience. To this end, we designed and conducted a user study on three visceral interfaces to educate users about their eye-tracking data. Our results suggest that while certain visualizations can be distracting, participants ultimately found them informative and supported the development and availability of such interfaces even if they are not enabled by default or always enabled. Our research contributes to developing informative interfaces specific to eye tracking that promote transparency and privacy awareness in data collection for VR.

Index Terms: privacy notice, virtual reality, eye tracking.

1 Introduction

Different interaction modalities continue to arise as the VR space continues to evolve. These interactions are facilitated through emerging technologies including hand tracking and gesture classification [42, 12], EMG sensing [34], voice [18], and eye tracking [53, 36]. While not all VR head-worn displays (HWDs) come with these features, they are becoming more prevalent in higher-end headsets that are available to consumers. For example, the Apple Vision Pro relies on gaze and pinch selection as the main mode of interaction. Eye-tracking data benefits the user experience and allows developers to create innovative new interfaces and features. However, including eye-tracking data as a standard stream of data requested by third-party apps has privacy implications.

Eye-tracking data within VR is typically captured using integrated camera sensors that capture the user's eye and projects a gaze position into the 3D virtual world. Eye trackers provide access to raw gaze positions, blink rate, and pupil dilation. Features extracted from this data can be used to gather intimate details about the user including gender, ethnic background, sexuality, and mental health conditions [30, 19]. While certain eye-tracking features—such as the iris biometric [20]—are protected by specific developer policies [33, 29], the data gathered from gaze position does not receive the same levels of protection. Terms and conditions agreed upon during the setup of a HWD may allow developers access to such data and may not provide protections against data recording, streaming, or processing. The language used in terms and conditions or privacy policies is difficult to understand by average users, resulting in users who may not be aware of what data is being collected and what it could be used for. Developers do care about user privacy, however, they are not equipped to build secure applications and features without the aid of a privacy expert and are not incentivized to do so [38].

Previous work on eye-tracking privacy has built real-time privacy systems or otherwise made technical advancements to protect user privacy in either datasets or at the sensor level [43, 44, 8, 9, 7, 50]. While these privacy-preserving systems are available, transparency on their use within industry products is not clear. For example, while Apple's philosophy on eye-tracking data within the Vision Pro is clear in that no gaze data is shared with anyone or is stored

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locally [3], Meta's white paper on eye-tracking privacy is clear only on their processing of eye images [33]. The paper states that Meta APIs only provide first and third parties with abstracted gaze data that encodes a numerical representation of gaze direction. However, the resolution of this encoding, any privacy noise mechanisms applied to it, or other access controls on this data are not clear. Furthermore, recent updates to the Quest telemetry service indicated that privacy-preserving methods are being applied to the data being transferred and stored on their servers, but the exact methods or implementation are not disclosed [35]. Thus, there are no standards on transparency for sharing gaze data in VR devices, enabling the risk of using aggregated gaze data to make inferences about users from first and third parties. We attempt to mitigate this lack of transparency by increasing awareness of the risks introduced by eye-tracking data to users through the design of privacy awareness interfaces specific to VR interaction [6, 41].

In this paper, we set out to design, implement, and evaluate visceral notice interfaces specific to VR eye tracking. The data collection environment and implementation scripts of each interface are open-source and can be found at `https://version.cs.vt.edu/privateeye/visceral-notices.git`. We measure the change in user perceptions of privacy awareness before and after experiencing our visceral notice interfaces within VR scenarios. Participants experienced a Permissions Request where they consented to enable eye tracking through friction introduced by forced head movements. Participants were also shown visualizations of their raw gaze during a VR exploration and selection task. These interfaces were designed to induce a visceral response to inform users of their eye movements while balancing user experience. Our interfaces informed participants about the types of eye movements they make and increased caution in their perception of data sharing for certain applications. Our major contributions are:

- Novel visceral interface designs for eye-tracking permissions requests and gaze visualizations that increase user privacy awareness by impacting the willingness to share data with employers and to support VR gaming and entertainment.
- Findings that the Tendril gaze visualization, while distracting, was informative about where a user was looking and actively influenced user behavior while viewing VR content.
- Design recommendation that privacy awareness indicators should be provided to new VR users or when eye tracking is first activated with the ability to toggle them on and off.

2 Related Work

2.1 Eye-Tracking Privacy

Adopting and standardizing eye-tracking technology introduces risks to user privacy based on the inferences the captured sensor data enables. The introduction of eye tracking as a research instrument has produced studies demonstrating how eye-tracking data can reveal a broad range of aspects about a user from their personality, medical conditions, age, gender, and ethnicity [27]. This includes initial explorations predicting age, gender, and identity in VR and augmented reality (AR) [46, 10, 43]. Research experiments linking eye movements to sensitive labels are typically executed on a small scale and use ideal conditions that enable clear classification. However, evidence of the environment in which gaze data can reliably predict such attributes informs the field that there are future risks to user privacy when eye-tracking data is collected at scale. We direct the reader to a survey from Bozkir et al. [4] for a full discussion on the scope of privacy risks introduced by eye tracking in VR.

Eye tracking is not limited to gaze direction, sometimes including pupil dilation and blink data [16]. An emerging trend from both eye-tracking providers and VR/AR platforms is restricting access to raw images of the eye and pupil diameter data to preserve privacy [33, 29]. For example, Meta Quest headsets will not allow developers to access eye images as they are proven to contain the iris biometric [21], but will share a numerical representation of the gaze direction that enables inferences on user behavior aggregated over time [33]. Recent research has suggested adding noise to data or limiting data access to specific eye movement features [10, 50], however, the adoption of privacy-preserving methods on consumer devices with eye tracking is unknown. Given the current trends of VR systems providing developer access to eye-tracking data with user consent—a notable exception being the Apple Vision Pro—our work focuses on increasing user privacy awareness through a visual interface integrated within the VR experience.

2.2 Privacy and Security Indicators

Despite the lack of knowledge surrounding the amount of data being collected, users still express the desire to customize data collection, including storage and retention as well as notifications and nudges [1, 15, 2]. Privacy policies are not written with users in mind. Rather, they are written with extensive jargon and exist to meet compliance standards and limit a company's liability; these policies are often confusing, ineffective, murky, and typically go unread [48, 40, 26]. Users can be manipulated into making privacy decisions that benefit the entity crafting the policy, even when the decision might harm the user [48, 40]. Simple text notices are inefficient, and developers must create novel designs for VR and iterate on such designs to improve user experience and adapt to emerging trends in VR design [26, 39]. Experts can be consulted to design icons and other visual representations to communicate complex concepts [17]. Users can be empowered through transparent data collection and gain the confidence needed to make the privacy decisions that best fit their needs [40, 39, 48].

Privacy indicators for VR are still in development. They can serve a variety of functions including informing users of eye tracking, motion tracking, other data collection, and indicating what entities may be safe or unsafe. Researchers have proposed several indicators such as colored outlines for virtual avatars in social VR indicating an avatar's authenticity or symbols above a virtual portal representing hyperlinking to different parts of the Metaverse [31, 51]. Some hardware developers in the XR space have called for such indicators to be present, such as with the Magic Leap 2 requiring developers to inform users when their eyes are tracked [29]. We identify the need for innovative deployments for privacy notice in VR and identify visceral notice as a promising concept relevant to eye-tracking data.

2.3 Visceral Notices

Calo [6] coined the term "visceral notice" to describe an experientially rich strategy for communicating privacy risks in emotionally impactful and sensorily resonant ways. He identifies three techniques as especially promising for raising privacy awareness. "Familiarity as warning" leverages users' familiarity with experiences that are so quickly perceived and easily interpreted that they are intuitively obvious. "Psychological response as notice" uses visual or audio stimuli that reliably trigger psychological responses that elicit caution; the goal is to make users aware and highlight vulnerabilities. "Showing" vividly depicts risks and adverse consequences, including ones tailored to individual users.

Because visceral notice uses psychology and design to directly target experience, Calo argues it can—in some relevant ways—outperform the dominant alternative: notice-and-consent terms of service agreements. Users cannot comprehend the legalese they are presented with and have no opportunity to negotiate, resulting in a quick acceptance to continue to their app or website [14]. Visceral notice provides an opportunity to increase user awareness by (1) capturing users' attention and motivating them to consider impor-

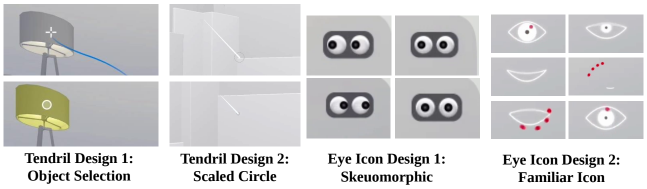

Figure 2: Tendril and Icon visualization designs.

tant information they may otherwise overlook or misunderstand, (2) simplifying complex privacy issues for users who may otherwise struggle to understand them, and (3) enhancing user autonomy to make more informed choices resulting in a reduction of the power imbalance between companies and users.

Selinger et al. [41] recently made the case for visceral notice within the context of VR-based eye tracking. The authors offered several possible visceral notice strategies for enhancing privacy awareness of eye-tracking risks in VR. To our best knowledge, the proposed interfaces have not yet been implemented or evaluated for validity with real VR users. In our evaluation, we execute a design phase to inform how to best implement visceral techniques within VR and evaluate them in a corresponding user study to produce results on whether they work as intended with respect to privacy awareness and behaviors and whether users find them annoying or detracting with respect to usability.

3 METHODOLOGY

The objective of our work is to design (§3.1) and evaluate (§4) visceral interfaces for eye tracking in VR. We pose high-level research questions on the effectiveness and usability of visceral interfaces to inform VR users of privacy risks (§3.2) and conduct a user study with prototypes of our interfaces to address these questions (§3.3).

3.1 Interface Design

Eye-tracking data is commonly visualized to support collaboration [54], visual analytics of recorded data [45], or to guide user attention in VR [52]. Visualizations of eye-tracking data for analytics include heat maps [22] and trail paths [37] to provide insights into gaze behavior. Our VR interface designs explore the lesser studied challenge of privacy awareness. Our design exploration process included two visual designers in graduate school for 3D design who produced iterative prototypes. The prototypes were critiqued by eye tracking, design, and privacy experts every other week over a span of four months. Traditional design principles for human behavior (e.g., the Hawthorne Effect [5] and friction [32, 13]) were used to seed the initial designs. Our prototypes targeted the most relevant scenarios related to privacy: an app permissions request to collect eye-tracking data and the exploration of two gaze data visualizations proposed by existing literature on visceral notices [41].

3.1.1 Permissions Request

This scenario aims to evaluate an extension of traditional permissions requests that apply to VR and eye tracking. Our design goal was to balance usability and current norms while also designing the interaction such that the user was informed about what they were consenting to and given time to genuinely make their decision.

The first design utilized an avatar of the user within the VR platform, where the avatar's eyes moved in tandem with the user's head movements (Fig. 1, Design 1). Design 1 leverages a visual modality to augment the typical text-based notice with a visceral feature by showing how eye movements would be relayed on a VR avatar. This design mirrors the eye-tracking consent process seen when setting up a Meta Quest Pro headset.

The second design introduced a novel interaction to perform the permissions request. The user is asked to rotate their head and stare at an eye icon until it turns blue to accept the request (Fig. 1, Design 2). This design tapped into both the technique of productive friction [13] to slow down the user and provide time to consider their actions in addition to the visceral feature of psychological response as notice. Head direction was used as a proxy for gaze direction as the user had not yet consented to data collection and any manner of acquiring temporary or limited consent to implement the design in practice was unnecessarily complex. The interface disrupts the usual acceptance flow with a physical movement and uses a fixed dwell time for selection to ensure the user's choice was a conscious decision and relay the responsiveness of gaze data.

3.1.2 Gaze Visualizations

Tendril Selinger et al. [41] used the term tendrils to describe rendered lines that trail a user's eye movements to leverage their innate attention to motion and draw attention to where their gaze data was recently directed. Tendril overtly reminds the user of their eye movements at all times. Such a visualization would generally be considered distracting as it occludes the VR environment and can disrupt the user. Thus, Tendril is designed to fade over time, building upon previous gaze trail concepts [45]. Our designs explored both obstructive and non-obstructive elements to implement Tendril and communicate to users where the data indicates they are attending to. To balance utility with a potential drop in user experience, one design focused on using the cue to denote which objects in the VR scene could be selected by the user (Fig. 2, Eye Tendril Design 1). Emerging design elements included a crosshair to minimize occlusion while providing semiotic meaning for focus and a dynamically scaled gaze disk to convey fixation information (Fig. 2, Eye Tendril Design 2). The design phase of Tendril primarily focused on identifying optimal time parameters for fading the gaze trail and determining which icon best relayed raw gaze data.

Icon The goal of the icon visualization is to leverage the visceral feature of "familiarity as a warning" to maintain user awareness that eye-tracking data is being recorded. For example, a red blinking dot is well understood to indicate that a camera or application is currently recording the user and taps into the Hawthorne Effect of behavior modification while being observed [5]. The first design presents a low-fidelity set of eyes in the top-right corner of the user's field of view, acting as a pair of eyes observing the user (Fig. 2, Eye Icon Design 1). The icon is skeuomorphic as it illustrates a pair of eyes animated with real-time data to mirror the user's eye movements. The second approach merges familiar iconography of a blinking red dot to signify recording with a blinking animation of an eye icon (Fig. 2, Eye Icon Design 2). The icon is presented in a fixed location relative to the user's field of view and occasionally "blinks" to remind the user of its presence via motion.

3.1.3 Takeaways

The design phase goal was to iterate on what an effective visceral interface should look like and generate study conditions for an end-user study. We determined we should explore the Permissions Request scenario with the Head-Based Dwell Selection interface. While the animated avatar relays info about how gaze data will be used, it does not diverge from the status quo of notice-and-consent pop-ups. Thus, the opportunity to leverage productive friction and evaluate whether users noticed the consent icon respond to head movement as if it was gaze data will provide new insights into VR privacy awareness interfaces.

Our design work produced Tendril and Icon visualizations expected to have high and low impact on user experience, respectively. We selected one design of each visualization for comparison in the end-user study. For Tendril, we decided to carry forward several of the design elements produced. The optimal fade parameter of 500 milliseconds was identified along with the clear benefit of the tendril interacting with game objects to balance utility and distraction when visualizing raw gaze data. For the Icon design, we

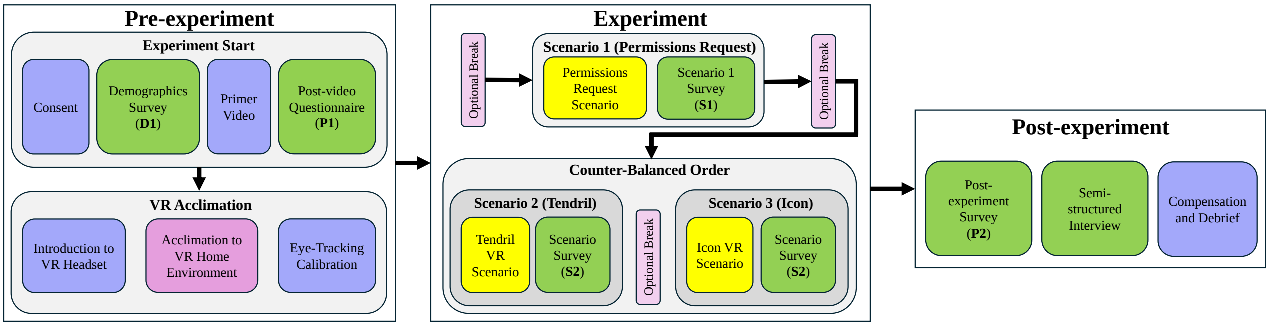

Figure 3: User study flow. Participants experienced the Permissions Request scenario before the counter-balanced ordering of tendril and icon.

decided to deploy the skeuomorphic floating eyeballs animated by eye movements. While the animated, familiar recording icon is effective at reminding the user they are being recorded, the visceral effect of two eyes watching you and mirroring your behavior was stronger; and we hypothesize it will be more effective at influencing user behavior during deployment.

The designs carried forward to our evaluation cover the "familiarity as warning" and "psychological response as notice" features of visceral notice, however, we do not evaluate any interfaces based on the "showing" techniques. Examples of such techniques include reporting to a user how often they looked at darker versus lighter skin tones among art models [41]. The design and implementation of strong visceral response from "showing" techniques relies on depicting actual harms, however; as no VR eye-tracking privacy harms have been publicly reported, the information relayed would be speculative. Thus, we focus first on benchmarking the Permissions Request scenario and comparing the Tendril and Icon interfaces to understand their first-order impact on privacy awareness, data sharing in different contexts, and willingness to enable or recommend the privacy-awareness interfaces.

3.2 Primary Research Questions

The focus of our work is to understand the ability of visceral notice interfaces based on eye-tracking data to impact the privacy perceptions of VR users. To achieve this, we provided participants with background knowledge on the potential privacy harms of sharing eye-tracking data and measure individual privacy perceptions before and after experiencing the interfaces. We also aim to understand if the impact of our visualization interfaces has a negative or positive perception among users as well as their impact on user experience. We summarize these points in the following research questions: RQ_1: *Do visceral interfaces increase privacy awareness or concerns for eye-tracking data?* and RQ_2: *Do users perceive and interpret each interface scenario differently, and do they prefer the Tendril or Icon interface for data visualization?*

3.3 User Study Protocol

Figure 3 illustrates the study protocol. Participants were asked to carefully read and sign an informed consent document describing the study purpose, methods, compensation, and data management plan. Participants then completed a demographics survey (**D1**) associated only with their unique subject ID. Participants watched a three-minute long primer video introducing them to how eye-tracking technology works, its potential benefits, and various privacy concerns based on Kröger et al. [27]. We asked the participants to complete a questionnaire on privacy attitudes and concerns (**P1**) immediately after the primer video to benchmark levels of privacy awareness before experiencing the visceral interfaces. Participants were introduced to the Meta Quest Pro VR headset and controllers by making selections within the Oculus platform menus. Participants performed the Quest Pro eye-tracking calibration once

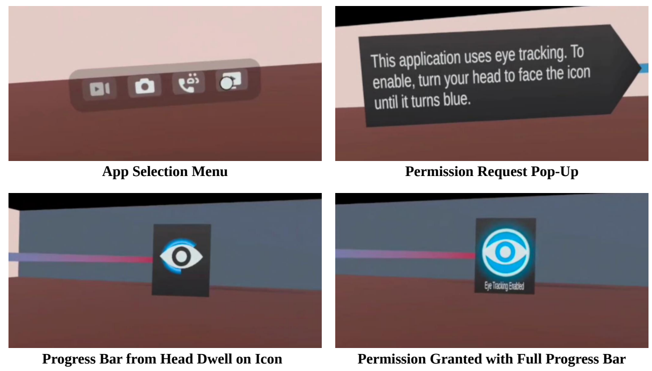

Figure 4: The evaluted permission request scenario.

they were comfortable using the device. The participant then observed a visualization of gaze data, consisting of a moving dot, to ensure the gaze estimates were accurate.

The participants were first presented with the Permissions Request scenario (Figure 4) which simulated launching an application from the Oculus home environment and receiving an eye-tracking permissions request. A virtual panel displayed four applications that the user could select with the hand controllers. Participants were instructed to launch each application individually and experience the resulting permissions request pop-up window. The pop-up window asked the participant to move their head towards the eye icon and hold their gaze over the icon until the blue progress bar filled up to enable eye tracking. The tracking data used to intersect gaze with the icon only used head orientation and not the eye-tracking data, as head data is enabled by default for VR applications. If the participant did not maintain their dwell over the eye icon long enough or they moved their head, the progress bar was reset. Once this process was completed for one of the apps on the menu bar, the selected app icon was removed and the participant proceeded to repeat the consent process until all apps had been launched. After the scenario, the researcher assisted the participant in removing the headset and the participant completed the Permissions Request scenario survey (**S1**).

Participants then proceeded to complete the Tendril and Icon scenarios. The order of these scenarios was counterbalanced across participants to counteract order effects. As shown in Figure 3, a common virtual environment consisting of an art gallery was used for both visualizations. The Tendril scenario visualized the user's raw eye gaze data while the Icon scenario displayed a set of floating eyes animated with the raw gaze data. The rendered Tendril would intersect with 3D objects in the virtual space and indicated exactly where the user was currently looking, while the Icon visualization was positioned at a fixed point within the user's field of view. For each condition, the participants were given four minutes to explore the virtual art gallery and select up to five art pieces they found the most interesting or enjoyable. Participants then removed the headset and completed the Tendril/Icon survey (**S2**).

Finally, the participants completed the post-experiment questionnaire (**P2**) and then participated in a semi-structured interview around the following three questions: *Which interface (Tendril/Icon) did you prefer?*, *Can you please elaborate on what factors influenced your decision on eye-tracking interface preference?*, and *Can you please provide additional feedback on how the presented interfaces could be improved or modified to better fit your needs as a user?*

Participants Participants ($n = 40$) were recruited from a university student, faculty, and staff population using an IRB-approved study protocol. Participants were compensated $20 USD for their time. Gender parity was maintained as 20 identified as women, 19 identified as men, and one identified as non-binary. The most common ethnicities were Asian (47%) and Caucasian/White (42%). All participants were between the ages of 18 and 39 years old, with 70% participants falling between the ages of 20 and 26. Most users (75%) had prior experience using a VR headset, primarily for education or gaming. Responses from five participants were removed from data analysis as they had indicated a simulator sickness level of "severe" for at least one symptom at any point in the experiment. The Simulation Sickness Questionnaire (SSQ) was administered during every survey prompt (**S1**, **S2**) [25].

4 Evaluation

Our evaluation of the VR visceral interfaces compared participant attitudes towards eye-tracking data before and after experiencing the interfaces as well as willingness to share data (§ 4.1), measured user experience after the permission request interface (§ 4.2), compared the Tendril and Icon interfaces (§4.3), and finally explored participants' gaze data and verbal responses as they encountered the interfaces (§4.4). Figure 3 illustrates the response data collected at each point of the study protocol used for the resulting analysis. A Kolmogorov-Smirnov test was used to determine the normality of the collected data for each response. All of the survey data, with the exception of the survey on attitudes towards the interfaces, were not normally distributed ($p > 0.05$). Thus, all statistical comparisons described in this section use a two-sided non-parametric Wilcoxon-Signed Rank test to determine significant differences for ordinal data. The exception was survey data for attitudes (Fig. 9) between interfaces that were analyzed using a paired t-test. A full summary of all survey questions is provided in the Supplementary Material.

4.1 Privacy Awareness and Data Sharing

To measure the impact of using visceral interfaces on privacy awareness (RQ_1), each participant completed survey questions before experiencing any of the VR scenarios (**P1**) and in the post-experiment survey (**P2**). Privacy awareness questions are based off of two Westin privacy indices [28] and prior eye-tracking based surveys [43, 28].

We analyzed the survey responses for attitudes towards eye-tracking data sharing and present results only from the prompts in which the median response were different before and after experiencing visceral interfaces. There were twelve total entities (in general, with government agencies (non-health), with a government health authority, with a local company, with an international private company, with a domestic private company, yourself (e.g., home cloud), with an employer's internal user, with a research institute, in exchange for benefits, to support VR applications (e.g., games, entertainment), to support further VR development (e.g., hardware)) and five had different pre and post median values (Q1-Q5 within Table 1). Figure 6 provides box and whisker plots comparing the pre-experiment and post-experiment responses for Q1-Q5.

Significant differences ($p < 0.001$) between before and after responses were only found for Q3 (employer's internal user) and Q5 (VR games/entertainment). Experiencing the interfaces shifted the responses for sharing with employers from disagree towards strongly disagree and from agree to neutral for supporting VR applications (e.g., games, entertainment). This result indicates that participant privacy attitudes were affected by experiencing visceral interfaces for these two applications. In summary, participants indicated they would not share eye-tracking data with non-health government agencies and employers (median responses of "Disagree"). However, they maintained neutral and positive scores for the other responses, indicating they are willing to share eye-tracking data in contexts even considering the risk to their privacy.

Table 1: Privacy awareness questions for the three scenarios.

Privacy Awareness	**Would you agree to...**
Q1	share your eye-tracking data with government agencies (non-health)?
Q2	maintain eye-tracking data yourself (e.g., home cloud storage)?
Q3	share your eye-tracking data with an employer's internal user?
Q4	share your eye-tracking data in exchange for benefits?
Q5	share your eye-tracking data to support VR applications (e.g., games, entertainment)?
Permissions Request	
Q6	It felt like the accept icon seamlessly responded to my head movements.
Q7	It felt like the accept icon seamlessly responded to my eye movements.
Q8	I felt I had control over my decision to accept the permissions request.
Q9	I was annoyed by having to rotate my head as part of the request.
Q10	I felt the head rotation was effective at bringing attention to eye tracking.
Tendril/Icon	**The eye-tracking interface...**
Q11	distracted me from my task.
Q12	informed me of which object I was looking at.
Q13	made me aware that I looked at objects I otherwise would not have realized I glanced at.

A set of questions related to participant willingness to share data for certain VR-specific services were asked during the post-study survey (**P2**) that were not asked during the post-video questionnaire (**P1**). Participants indicated they did not want to share their eye-tracking data to analyze their shopping behavior or identify interests to facilitate shopping assistance or advertisement: the median for both questions indicated "Disagree". In contrast, participants indicated their preference to share their eye-tracking data in order to improve or analyze reading skills, enable hands-free interaction, monitor stress levels, detect disease, facilitate learning, type or make selections with their gaze, and improve user interface interactions: median scores for such questions were "Agree", with the exception of "Would you agree to share eye-tracking data for early detection of mental and psychological disease like dementia or Parkinson's?" which had a median score of "Strongly Agree".

4.2 Permissions Request

To evaluate user perceptions of the Permissions Request scenario (§ 3.1.1), survey questions (**S1**) were collected after experiencing the scenario. Survey responses characterized the user perceptions of the head-based acceptance of a permission request (RQ_2). TLX results indicated low mental and physical demand and high performance. Please see the Supplementary Material for these results.

Participants were also asked about the usability in regards to accepting the permissions request (Q6-Q10 in Table 1). Figure 7 shows that participants mostly agreed that the accept icon responded to eye movements, despite head direction being used to

Figure 5: The Tendril and Icon visual interfaces were deployed in an art gallery and the participant selected up to five favorite paintings.

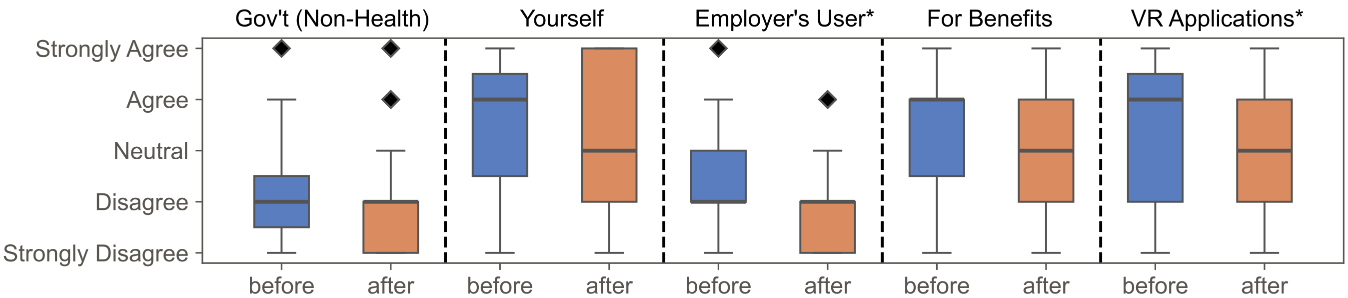

Figure 6: User willingness to share eye-tracking data for different applications. Significant differences ($p < 0.05$) indicated with an asterisk (*).

initiate the interaction. This result indicates that head data could be used as a proxy for eye movements in this type of visceral interface if the user has not consented to sharing gaze data yet. Participants were not annoyed by having to move their head to accept the permissions request and indicated head rotation was successful at bringing attention to eye tracking.

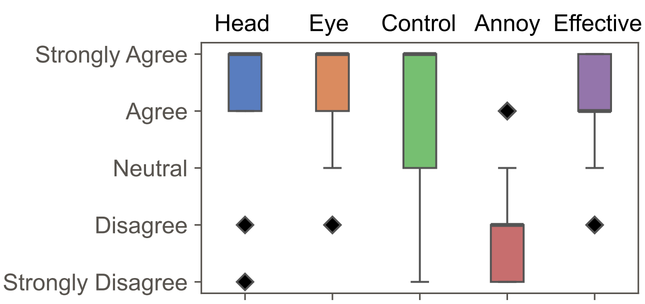

Figure 7: Usability scores (Q6-Q10) for the Permissions Request interface. The results suggested participants found the interface usable. Note, Q9 asked if the interface was annoying.

4.3 Tendril/Icon

The Tendril and Icon interfaces were compared within the art gallery VR experience (§3.3). Semi-structured subjective responses after using each interface (**S2**) and at the end of the study were used to compare perceptions and preferences between interfaces (RQ_2).

4.3.1 Which interface (Tendril/Icon) was more effective in informing users?

We surveyed participants on how each of the two interfaces informed the user of what they were paying attention to (Q11-Q13 in Table 1). Figure 8 shows subjective responses for how well each interface informed users on their attention allocation. Participants found the Tendril interface to be distracting (Q11), informative by indicating which objects they were looking at (Q12), and increasing their awareness of objects they would not normally attend to (Q13). In other words, even though Tendril was considered distracting, it was significantly better than Icon at informing users of how they allocate their attention. This result is expected, as Tendril by design maps gaze data into the environment while Icon only plays back the animations. Qualitatively, participant S017 stated, "I just enjoyed knowing exactly where my eyes were looking so I could take note on what I'm unconsciously looking at, and I just feel it had the better method for the purpose of showing the user eye tracking." In contrast, they did not find the Icon interface to be distracting (Q11) nor did they find it to inform them of what objects they were looking at (Q12). All of these results were statistically significant between Tendril and Icon ($p < 0.05$).

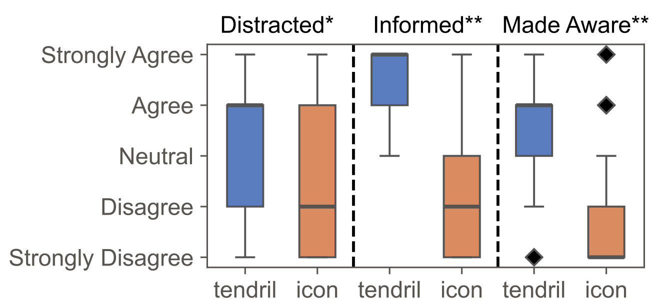

Figure 8: Participant scores for how distracting (Q11) and informative (Q12 & Q13) each interface was. Significant differences ($p < 0.05$) and ($p < 0.01$) are indicated with an asterisk (*) and double asterisk (**), respectively.

4.3.2 Which interface (Tendril/Icon) had better usability?

NASA-TLX response data was collected after using each interface to compare user experience. No significant differences were found ($p > 0.05$), though participants indicated higher levels of physical demand and frustration for the Tendril interface. Please see the Supplementary Material for these results.

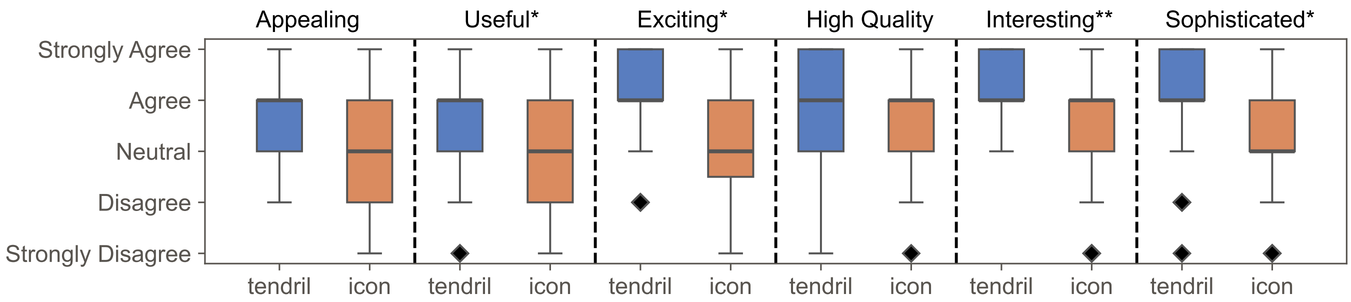

Figure 9: The attitudes assessment results for the Tendril/Icon interfaces. Significant differences ($p < 0.05$) and ($p < 0.01$) are indicated with an asterisk (*) and double asterisk (**), respectively.

4.3.3 Which interface (Tendril/Icon) do participants prefer?

Participants indicated their attitudes towards the interfaces (**S2**) after experiencing them in the VR art gallery task; attitude assessment was based on prior studies assessing interfaces [24]. We compared the responses to determine if one was preferred more than the other. Figure 9 plots the attitudes data for each interface. We performed a paired t-test to test for any difference between the mean attitudes participants felt towards each interface. The Tendril interface had significantly higher ($p < 0.05$) scores for how useful, exciting, and sophisticated the interface was. No significant difference was found for appeal or quality. Participants found the Tendril interface more interesting in comparison ($p < 0.01$). Despite the increased mental load of the Tendril interface, 63% of participants indicated a preference for the Tendril interface.

4.3.4 Which interface (Tendril/Icon) would users enable?

Results indicated participants would not leave the Tendril interface enabled, provided it was the default setting with a median score of "Disagree". Participants indicated a median score of "Disagree" for choosing to enable the Icon interface. Participants selected "Agree" and "Strongly Agree" to have the ability to toggle the Icon and Tendril interfaces accordingly. Participants also indicated "Disagree" for enabling both Tendril and Icon interfaces within all VR applications. No statistically significant results were found.

Participant S009 reported, "Toggle off feature [for Tendril], so that [the] user does not get conscious about it and do the task without being known that it's following. The freedom of looking at objects is lost here, [it] should be less assistive or present on the screen." In another example explaining why participants made this decision, S013 reported, "I think when it comes to privacy I like to know when and what is being tracked. If VR is using my eye-tracking data then an icon on the screen should be present to inform the user that their data is being collected. Both the presented icons would work but I would suggest the pair of eyes icon because it stays out of the way of the user while still being present indicating that eye tracking is happening."

Participants indicated an agreement that interfaces like these should be shown to users before enabling eye-tracking technology as well as developers providing interfaces like these to indicate what types of eye-tracking data is being collected (median scores of "Agree"). In other words, these interfaces would best be suited for tutorial scenarios to introduce the technology and data collection. These interfaces would then be turned off after the tutorial but could be re-enabled at user discretion.

4.4 Eye-Tracking Data

We computed how long participants spent looking at paintings between conditions and tracked the number of paintings they selected or deselected (Figure 10). In the Tendril condition, participants had an average dwell time of 3.3 minutes (std dev. = 0.3) and 3.1 minutes for the Icon interface (std dev. = 0.6). No significant differences were found for either metric between conditions ($p > 0.05$). In the Tendril condition, participants had an average number of selections and deselections of 5.0 (std dev. = 2.6) and 4.9 for the Icon interface (std dev. = 2.4). No significant differences were found ($p > 0.05$). Based on these results, the visual interface did not have a significant impact on how users interacted with their environment, but did introduce additional outliers with lower dwell times in the Icon condition.

Participants also provided feedback on how the interfaces influenced their gaze patterns. Participant S007 reported the tendril condition was "very uncomfortable" as they were very self-conscious of where they were looking and avoided looking at certain areas on an art piece, including nude imagery. Participant S021 stated that, even though they did not avoid looking at anything in particular due to knowing their eyes were being tracked, they felt it was "creepy". Participants S004, S014, and S028 all verbally expressed their disdain for the Icon interface, remarking "Oh God!", "Oh I hate this,", or "Why would you use it and have two eyeballs staring at you?".

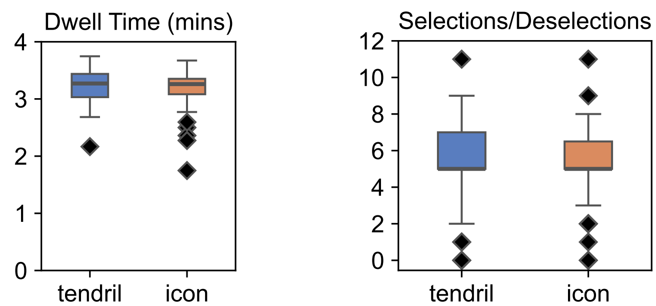

Figure 10: Dwell time (Left) and number selections and deselections (Right) between the Tendril/Icon interfaces.

5 Discussion

We designed and evaluated visual visceral interfaces of eye-tracking data. We first explored a Permissions Request scenario, in which participants responded positively towards a head-based dwell selection interface. NASA-TLX scores indicated participants did not find the task demanding nor did it incur a large effort to perform. In addition, participants reported the Permissions Request interface responded to their head movements, agency in the ability to accept the request, were not annoyed at rotating their head for the request, and found the head rotation brought their attention to eye tracking. This indicates an interface can be created to inform users of eye tracking *without* enabling eye tracking. Interestingly, participants reported the permissions request responded to their eye movements despite the request itself using head direction, *not* eye movements as part of the acceptance routine.

We also wanted to explore user reactions to visceral interfaces and assess if the presence and interaction with visceral interfaces increased privacy awareness among users. The implications of our results for each research question are described below:

RQ_1: Do visceral interfaces increase privacy awareness or concerns for eye-tracking data?

Experiencing the interfaces shifted the responses for sharing with employers from disagree towards strongly disagree and from agree to neutral for supporting VR applications (e.g., games, entertainment). This result indicates that participant privacy attitudes were affected by experiencing visceral interfaces for these two scenarios. During the post-study surveys, participants were inclined to not share eye-tracking data with non-health government agencies and employers (median response was "Disagree"), but maintained neutral and positive scores for the other responses. Experiencing visceral interfaces influenced participants to be more likely to withhold or be less likely to opt into data collection.

RQ_2: Do users perceive and interpret each interface scenario differently, and do they prefer the Tendril or Icon interface for data visualization?

Users were particularly disturbed by the Icon condition. Interestingly, while participants were distracted by the Tendril condition, participants found it informative and increased their awareness of what they were viewing: resulting in some users who avoided looking at nude regions in art pieces. In addition, participants preferred it over the Icon condition. Participants indicated both interfaces should not be enabled by default, though they indicated there should be an option to toggle such interfaces and they should experience them during the consent process. Further research is needed to identify what components of the visualizations influenced participants most, as the Icon condition was considered creepy due to the floating eyes while Tendril focused on the level of information about gaze data provided by the interface.

5.1 Implications

Given these insights, we suggest developers consider these designs when developing eye-tracking interfaces. For example, the Magic Leap 2 requires developers to provide such a visualization when eye-tracking data is being collected, stored, or used [29]. We recommend that developers consider using visceral interfaces to allow users to understand different types of data collection before enabling them. Specifically, data from our Permissions Request scenario suggest that using head direction effectively relayed information to users about eye-tracking data, despite eye-tracking data not being enabled. We note these interfaces may have the most impact as a training tool for audiences beyond general users, such as policymakers or developers transitioning from mobile apps to spatial computing. While specific users may not care about their own privacy, the ability to educate policymakers and inform regulation could have a broader impact. If visceral interfaces are used in practice, it is important for developers to indicate or remind users that data is still being collected even when the visual interface is disabled. We also suggest these options should be separate, that is, a user can opt-in to visualize their data through interfaces such as these while also opting out of the recording or transmission of data.

Users should be aware of the plethora of data collection methods in XR and should not rely only on what interfaces the developers create to visualize data collection. Users should become familiar with different privacy risks and check their permissions on their applications. However, not all applications ask or report what data is collected. In cases where they do, developers may not be transparent in all data that is collected [47]. As data collection of XR users continues to grow and become more pervasive, policy needs to be drafted to protect users while also encouraging innovation [11]. We see our interfaces as a stepping stone towards tools that promote transparency in data collection and have the potential to positively influence privacy awareness and decision making.

5.2 Limitations

Despite achieving gender parity, we did not have a diverse population. Most participants were college-aged students within STEM fields or had prior VR experience. In addition, there was a high percentage of Asian and White representation within this study. Further research is required to see if these findings can be replicated with more diverse populations or cultural backgrounds. Furthermore, we used a prototyped VR scene that emulated a VR home environment but does not perfectly replicate a VR operating system such as Meta's Horizon OS. Our study considered a task similar to exploring a game environment. Further research is needed to see if participants react similarly during different tasks, perhaps one where the visualization of eye movements would be beneficial, such as a shooter-type game or a game based on precision. Uses for these interfaces were explored more generally rather than specific consumer or enterprise use cases. The study results also do not capture the long-term effects of interacting with the interfaces. The number of visceral interfaces evaluated was limited to balance the study duration and avoid subject fatigue.

5.3 Future Work

Future work should focus on refining visceral interfaces and identifying different use cases for them. Additional studies could explore if participants react similarly during tasks beyond the art gallery search task, perhaps one where the visualization of eye movements would be beneficial such as a shooter-type game [50]. Evaluating the designs in VRChat or other social applications would also inform the ability to change user behavior in different applications. We did not evaluate interfaces that tapped into the "showing" category of visceral notice [41], and could explore such designs in future studies while simulating the expected privacy harms. Our gaze visualizations also show only raw data, and we hypothesize that visualizing privacy mechanisms being applied to the data stream [10] could be useful to provide transparency into what mechanisms, if any, the VR platform is using. For the eye icon, the user could only observe real-time data and would not see past eye movements animated on the icon. Future evaluations could add a delay to the animation to inform users of their past eye movements. The interfaces can also be extended to trigger in response to specific events or periodically during the task as a reminder.

Based on our design recommendation that users should be able to toggle visceral interfaces on and off, we are interested in exploring whether users forget that eye-tracking data is being collected when the visualizations are disabled and seek to validate that users understand their data is still being collected even when they are disabled. We suspect a nudging-based approach could be used to augment our visceral interfaces and effectively increase and maintain privacy awareness for VR users [1]. The ability to individualize privacy indicators and nudges also provides an opportunity for further enhancing the potential to adopt visceral notices in VR [49]. Finally, expanding out visceral interfaces into new sensors, such as brain-computer interfaces [23], as well as mixed-reality devices provides opportunities to address emerging privacy challenges.

6 Conclusion

We sought to design, implement, and evaluate informative eye-tracking interfaces to promote transparency and privacy awareness in data collection for VR. While certain visualizations can be distracting, participants found the interfaces informative and supported the development and availability of such interfaces regardless of whether the interfaces are enabled by default or not. We provide design suggestions for developers to create interfaces that are informative and transparent in data collection. As data collection becomes more pervasive in XR, it is imperative users are able to provide informed consent backed by policy that encourages transparency and innovation.

Acknowledgments

Authors acknowledge support from the National Science Foundation CSGrad4US Fellowship (CNS-2240205), the Virginia Tech New Horizons Graduate Scholars Program, and a gift from Meta.

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