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Don't Miss Notifications: Exploring Gaze Notifications for Virtual Reality Cooking Environment

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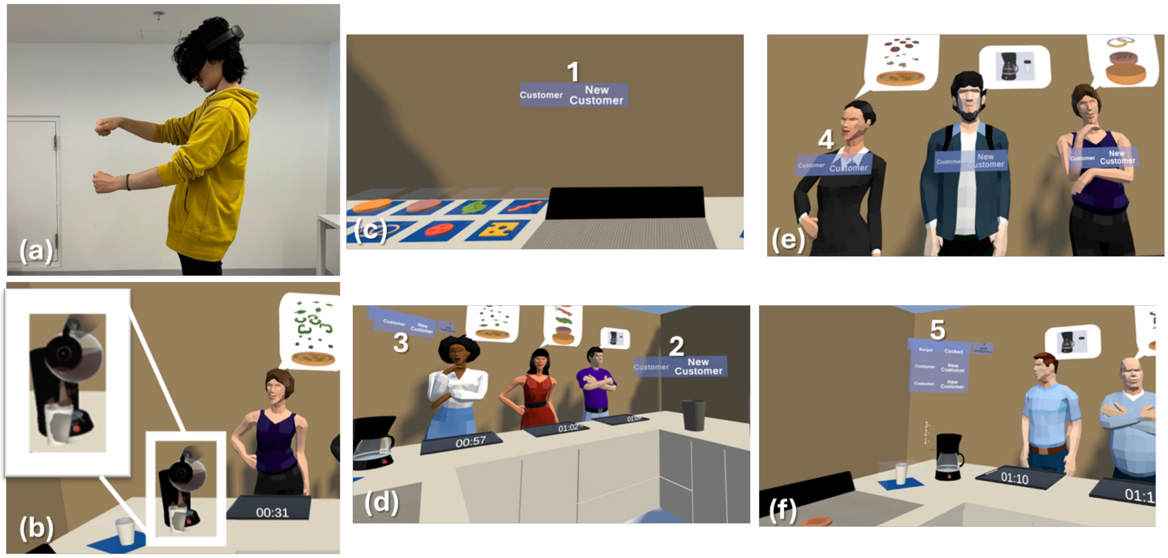

Figure 1: a) A participant pouring coffee and b) a similar scene in the virtual experiment environment. Notification types: c) GazeCue where notifications appear at gaze position (1) for 3 seconds. d) Gaze+Dock: notifications are shown at both gaze position (2) and on a fixed-position dock (3). e) onObject where notifications (4) are attached to the object itself. f) onDock: Notifications are shown on a fixed-position in the virtual environment (5).

Abstract

In 3D environments, designing efficient notifications is crucial for capturing user attention. While visual notifications -such as object-attached and fixed-position ones- are commonly used in virtual environments, they often require users to shift their gaze away from task-relevant areas, which can interrupt workflow and delay responses. To address these limitations, we designed two gaze-based notification techniques to provide responsive and intuitive notification in a virtual reality (VR) cooking task. We evaluated four different notification types: two world-fixed notifications (onObject and onDock) and two gaze-based methods (GazeCue and Gaze+Dock) with 16 participants. Our results show that participants performed better in using gaze-based notifications compared to world-fixed ones. Questionnaire results indicated higher usability, greater perceived presence, and lower cognitive load for gaze-based notifications. These results highlight the effectiveness of gaze-based notification techniques in VR by reducing the need for visual search and minimizing cognitive load. Our findings provide insights for developers or engineers to design more intuitive and responsive user-interfaces for 3D environments.

Index Terms: Notification, Virtual Reality, Gaze, Visual Feedback.

1 Introduction

Virtual Reality (VR) has become a widely used platform in various applications, ranging from gaming, training, and entertainment [24, 40]. During interactions with VR applications, users often engage in multitasking as they regularly switch between tasks, such as responding to a system notification while working on other activities. A critical update or warning on system status, safety alert, or instructional cue can be critical for successful task completion. Current Head Mounted Displays (HMDs) can deliver such notifications at any time and in any location in virtual environment [27], commonly as notification windows to alert users [44].

Although notifications may disrupt user attention and hinder task performance, well-designed notifications can support successful task completion by reducing cognitive load and anxiety, especially in tasks that require time management and constant monitoring [21]. However, designing effective notifications can be challenging, as they may become distracting [9], lead users to make errors [2], or remain unnoticed and leads inattention [26]. Designers and developers must, therefore, carefully consider notification design strategies that balance noticeability, minimize distraction, and preserve users' sense of presence. While extensive research has explored the trade-offs between noticeability and distraction in notification design for 2D interfaces [28, 12, 33, 30], these approaches do not directly translate to immersive 3D environments. Unlike 2D screen-based systems, immersive Augmented Reality (AR) and VR technologies allow digital content to be embedded directly into a

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user's virtual surroundings- not on a constrained 2D surface, so it makes it more challenging to design the notifications in 3D space.

As HMDs continue to evolve, notification designs for AR and VR systems are still an open research topic. Researchers have been investigated where to display [18, 45, 23, 44, 42], when to display [6], and how to display [13, 14] visual notifications. While these studies offer valuable insights, many rely on static notification placements that do not account for the dynamic nature of user attention shifts in immersive environments. Fixed-position notifications can become less noticeable when users frequently shift their gaze or move within the virtual scene. In contrast, attaching notifications directly to the headset may improve noticeability but often breaks immersion and disrupts the user experience, especially when they occlude with other objects. This highlights the need for adaptive notification strategies that can dynamically respond to users' attention and field of view (FoV). Previous work [19] investigated gaze data for unobstructed notification placement, suggesting that adaptive notification placement is especially important during demanding tasks. However, these notifications did not follow the gaze movements of the users. In this context, well-designed gaze-based notifications present a promising approach for delivering adaptive notifications, improving noticeability while minimizing distractions.

In this paper, we designed two gaze-based notifications for a VR cooking task, where users must manage their time and monitor various events, such as burning food, as a demanding task. The first, GAZECUE, displays a notification where the user is currently looking, and it remains visible for 3 seconds. The second, GAZE+DOCK, shows the notification both at the user's gaze location and at a fixed position in the scene. Prior work [45] found notifications attached to the VR headset have a better effect on user performance and immersion but are more disturbing.

In this paper, our goal is to design and evaluate whether gaze-based notifications could provide a better balance between noticeability, task performance, and cognitive load in dynamic VR tasks. To achieve this goal, we adapted a AR cooking task ARtisan Bistro, an open-source AR system designed for interactive cooking tasks [5], into VR. A previous study by Raikwar et al. [42] used a similar setup in AR to evaluate fixed-position visual notifications. Using this framework, we re-created the task for VR to investigate gaze-based notifications. We compared our two gaze-based techniques GAZECUE and GAZE+DOCK with the ONOBJECT and ONDOCK visual notifications that is investigated in Raikwar et al. [42] study.

This paper contributes to designing VR notification systems by presenting two different gaze-based notifications that follow users' gaze movements. These notification designs aim to display visual notifications by improving task performance without increasing cognitive load and breaking the presence.

2 RELATED WORK

2.1 Notifications

Notifications can be defined as *alerts* outside the user's focus and can take the form of visual, auditory, haptic cues or combination of them [21, 9, 20]. They became a core interaction in many digital devices [35], and it is important how to deliver them without leading distraction [9], performance loss [10], or inattention [26]. Yet, unlike 2D screens, HMDs require different notification design approaches as the user interacts with the 3D environment, creating new opportunities for designing notifications for AR/VR systems.

Previous work has explored various aspects of notification design in immersive environments. These include investigating the position of the notifications [18, 45, 42]. Rzayev et al. [45] investigated four different notification placements: attached to the VR headset, attached to the controller, floating in the environment, and fixed-position. Their results showed that notifications attached to the headset significantly increased noticeability and improved response time. However, this approach also led to increased cognitive load, as these notifications directly occupy the user's FoV. Another study [18] also investigated the position of the notifications in VR. They found that participants' recall of notifications was influenced by more than just the intensity of VR engagement. Low recall rates were sometimes due to participants not seeing the notifications at all, or only partially perceiving them due to suboptimal placement. This issue especially happened in time-sensitive VR scenarios. Although notifications were presented for a fixed duration of 12 seconds, participants frequently missed them—– not because they failed to perceive them –—but because they consciously prioritized VR content, choosing to focus on the ongoing task to avoid missing important elements of the experience. These findings emphasize the challenge of delivering effective notifications in immersive environments, balancing the need for noticeability without increasing cognitive load.

Raikwar et al. [42] investigated combining visual and audio notifications for AR tasks. They compared two visual notifications: attached to the related object, and one world fixed-position where all notifications are displayed in one accessible place by swiping down on the screen as in the smartphones. Their findings show that visual notifications positioned above objects and accompanying audio outperformed in terms of noticeability and cognitive load. These results highlight the importance of notification designs in 2D systems are not always applicable to 3D devices. Ghosh et al.[13] introduced haptic notification delivery in VR. Their findings showed that although haptic cues were perceived as less intrusive, they indicated that purely haptic notifications were often difficult to comprehend, and their patterns were not easily distinguishable, specifically in multitasking scenarios. Plabst et al. [37] explored notification placements in AR and non-AR environments. They compared *wrist*, where notifications are displayed on the wrist of the user, *world*, where notifications are over the current task, *heads-up*, where notifications are fixed to a specific position in the display of the headset, and *subtitle* is placed at the bottom center border of the FoV. Their results showed that displaying notifications over the objects resulted in higher usability, yet heads-up display performs better in terms of noticeability but increases distraction, similar to the previous finding ([45]). These studies highlight a consistent trade-off in immersive notification design: while heads-up notifications may improve noticeability by remaining consistently within the user's FOV, they also tend to increase cognitive load and user distraction. This points to the need for alternative approaches that keep visibility within the FOV for important tasks, while minimizing their effect on the user's cognitive load.

While integrating notifications into immersive environments, maintaining user presence is another important consideration. Studies have shown that static placement of notifications can disrupt presence by breaking the user's immersion [19]. For example, Rzayev et al. [45, 44] found that heads-up displays, despite their high noticeability, can negatively affect the user's sense of presence. In contrast, alternative placements such as on the wrist [37] or on the controller [18, 45] were shown to support presence more effectively, yet they often lack sufficient noticeability. Moreover, Hsieh et al. [18] noted that controller-attached notifications, although helpful for maintaining presence in static tasks, became disruptive when the task required frequent controller movements.

These findings highlight the need for notification designs that ensure visibility without overwhelming the user or disrupting their sense of presence—especially in dynamic, task-oriented VR tasks.

2.2 Gaze-Based Design

In Human-Computer Interaction (HCI) gaze modalities are widely used technique as it provides novel opportunities for gaze responsive interaction [41, 22, 34]. Previous research on eye-gaze interaction in VR has demonstrated several advantages in terms of task performance and user experience. Eye-gaze interactions enable faster, more efficient actions and accessible [3, 39], with gaze movements reaching speeds of up to 900 degrees per second [1]. This high speed allows users to perform tasks more quickly. Furthermore, the use of gaze requires less physical effort, as it reduces the need for muscle movement, making interactions less physically tiring [47]. Moreover, gaze provides a more accurate and immediate indicator of user attention [32].

Ilo et al. [19] introduced Goldilocks Zoning (GZ), a gaze-aware notification technique for VR that uses recent gaze history to find an optimal placement close to where the user tends to look, but not directly in their line of sight. While this method aims to reduce disruption by avoiding direct interference with the task, their results showed that some participants reported missing notifications or not noticing them immediately in GZ. Therefore, this approach may be less effective in scenarios where users rapidly shift attention, as it relies on recent gaze history rather than immediate gaze position. Their findings highlight the potential of using gaze behavior for building adaptive and context-aware notification systems.

Lu et al. [29] proposed Glanceable AR, introducing gaze-based and head-based interfaces for lightweight information access in AR. Their findings showed that while gaze and head interfaces helped reduce visual clutter, they were less effective for frequent interactions due to added cognitive and physical demands. While they explored gaze-triggered access through a gaze-based mechanism, their design required users to maintain fixation for a short duration to reveal content, which led to slower interactions, increased eye strain, and reduced user preference during frequent use.

Plabst et al. [36] investigated notification interactions with different multi-modalities including Gaze+Speech, Gaze+Pinch, Point+Speech, Point+Pinch and Touch only in the AR cooking environment [5]. They reported that gaze-based interaction was the least preferred, as participants found it unreliable, particularly because the headset often failed to recognize where they were looking, especially when attempting to select buttons. Similarly, unimodal gaze-based interaction for notifications has been studied by Plabst et al. [38]. Their findings highlighted several limitations of gaze-only interaction: participants reported lower usability and preference compared to touch-based interaction, citing frequent issues with eye-tracking reliability. Users described unintentionally selecting items and struggling to maintain focus on the notification, often causing interaction delays or errors. Unlike their work [38, 36], which focused on gaze as an input method, our study used gaze as a spatial anchor for notification placement.

The novelty of our work is, unlike prior studies that use gaze as an input method (e.g., gaze + speech or dwell-based interaction) [38, 36], our approach treats gaze as a spatial anchor for dynamically positioning notifications. Rather than relying on gaze history [19] or requiring fixation for activation [29], our system places notifications directly at the current gaze point and adjusts their position in real time. This key design decision improved both user performance and user experience, as supported by our quantitative and qualitative findings. To the best of our knowledge, this is the first study to demonstrate that using gaze direction dynamically for notification placement, not interaction, can improve performance and reduce cognitive load. Thus, the contribution of our work lies in the efficiency and adaptability of gaze-based notification placement in multitasking VR scenarios.

3 MOTIVATION & HYPOTHESES

Previous studies have explored the *static* notification placements in VR/AR systems[18, 45, 23, 44, 42, 19]. While these approaches offer valuable insights, *static* positions for notifications are often less effective where the user's FOV frequently shifts. In such scenarios, notifications anchored to fixed positions in the virtual environment can go unnoticed, especially when the user's attention is directed elsewhere. On the contrary, positioning the notification where the user is looking can increase the noticeability of the notifications.

Additionally, displaying notifications in world-fixed positions stays being less noticeable, especially when the user's attention is directed elsewhere in large task environments. This might require additional visual search, which increases the cognitive load. Since gaze and attention are highly correlated, placing the notification where the users look can reduce this visual search time and, thus, the cognitive load.

Displaying notifications attached to the headset, increases the noticeability but risks disrupting user presence, as it can feel intrusive –especially when gaze and head movements are not always synchronized. A notification placed based on the head position can occlude the objects in a virtual environment and disrupt the task execution, breaking immersion.

Overall, current visual notification systems in VR lack at least one of the aspects: noticeability, low-cognitive load, and presence. Gaze-based notifications, when designed properly, offer a promising alternative: they can improve noticeability while minimizing distraction and preserving immersion.

To address these limitations, we designed two gaze-based notifications, and we hypothesize that:

H1 *Gaze-based notifications improve task performance and notification noticeability.*

H2 *Gaze-based notifications improve user experience in terms of usability, cognitive load, and perceived presence.*

4 METHODOLOGY

4.1 Environment Settings

In this study, we adapted ARtisan Bistro –an open-source AR cooking environment task designed for researchers to evaluate user interfaces [43, 5]—- into VR. We selected this setup to build upon previous research and reproducibility and simulate a familiar cooking scenario that might be familiar to a wide range of users. We chose the same serving tasks that is used in previous work [42, 37]. In this environment, there were 3 main cooking stations: burger station, pizza station, and coffee station, as shown in Figure 2(a).

Burger Station: Participants were asked to prepare a burger using a patty, a bottom bun, a top bun, and three randomly selected ingredients from a set of five (Figure 2(b)). The patty is placed on the grill to cook, and the burger is completed based on the customer's requested ingredients. There are three different cooking states for the patty: uncooked, cooked, and burnt. Each state is set to take 10 seconds to complete.

Pizza Station: For pizza, participants were first asked to place the pizza dough in the preparation area (Figure 2(c)). Then, based on customer requests, they grabbed ingredients from a set of five and placed them on top of the dough. Afterward, they had to place the pizza in the oven. The pizza also has three different cooking states: uncooked, cooked, and burnt, with each stage taking 10 seconds to complete.

Coffee Station: To prepare coffee, participants were instructed to press the button on the coffee maker (Figure 1(b)). Next to the machine, there was a gauge with three levels, each designed to fill one cup. Participants took a cup from the designated area, picked up the pot from the coffee maker, and poured coffee into the cup. Filling a full cup was set to take 10 seconds. Once the cup was full, its lid was activated, indicating to the participant that the coffee was ready to serve. The coffee maker was configured to fill a maximum of three cups at a time.

Aside from these three tasks, there were a total of 12 available customer meshes, with 3 female and 3 male customers randomly selected among them for each session. Each participant was assigned to serve a total of 6 customers, with a maximum of 3 customers arriving at the same time. Each customer would wait for a maximum of 2 minutes, and if the participant failed to serve them within that

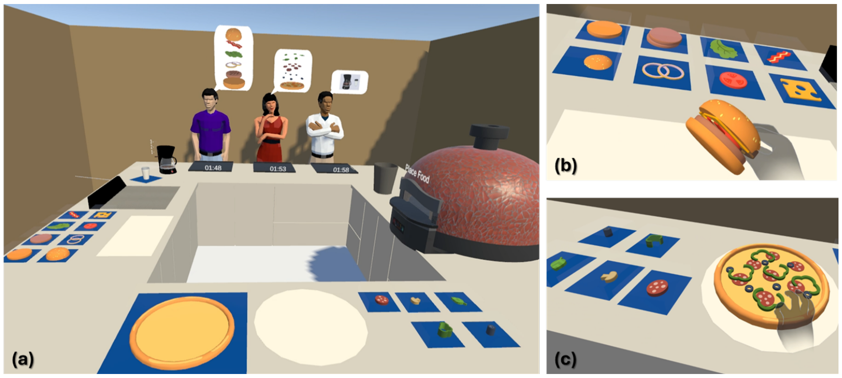


Figure 2: a) Complete experimental setup without notifications. b) A prepared burger and c) An uncooked prepared pizza.

time, the customer would leave. The remaining time was displayed on a tray in front of each customer to inform the participant.

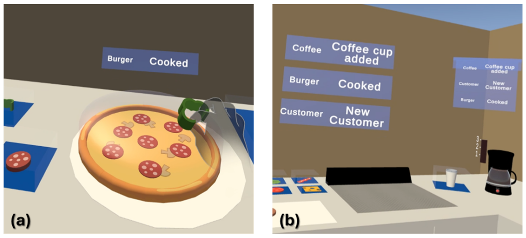


Figure 3: Gaze-based notifications: a) GazeCue: Notification is shown at gaze position. b) Gaze+Dock: Notifications are shown at both gaze position and on the dock.

4.2 Notification Design

We designed two gaze-based notifications, GazeCue and Gaze+Dock, and compared them with two world-fixed notifications (onObject and onDock) from the previous study that showed higher usability and efficiency [42], resulting in a total of four notification types. As in the implementation of the previous study [42], all notifications were displayed in the Station Message format. The "Station" indicated which station the notification belonged to, while the "Message" provided the relevant information as shown in Figure 1(c, d, e, f). We also followed previous work's suggestions [25] and set the number of words between 2-5. These short groups of words allowed users to read notifications comfortably in VR environments. The notification panel has dimensions of 12 × 3 × 0.5 cm in world space, corresponding to its width, height, and depth, respectively. We used blue transparent notification panel with white and bold text as in Figure 3 and Figure 4. Lastly, we did not include any sound effects for notifications.

onObject*:* Similar to the previous work's implementation [42, 50], notifications are shown on top of the related object, e.g., when the burger is burnt, the notification appeared above the burger (Figure 4(a)).

onDock*:* The dock notifications are inspired by smartphones' notification systems and implemented for virtual environment by Raikwar et al. [42]. We used the same design in our user study. In this notification design, notifications are displayed at a fixed-position (Figure 4(b)). We used the same notification position as the previous work [42].

GazeCue*:* The Gaze notification was set to appear 1 meter from the user's gaze position and tracked their eye movements for 3 seconds before disappearing. This duration was chosen based on pilot study results, which identified it as the optimal timing before disturbing the user and enough to notice the notification. If the user was looking downward and their gaze position was below the table, the notification was adjusted to appear above the table to prevent missing notifications (Figure 3(a)). If more than one notification appears at the same time, the newest one appear on the top of the previous one.

Gaze+Dock*:* For this notification, we combined the GazeCue and onDock notifications. The notifications were set to appear simultaneously both in the dock and 1 meter from the user's gaze position. Unlike GazeCue notification design, notifications stay user's gaze position until they dismiss them. To dismiss the gaze notifications, users were required to click on the corresponding notification in the dock, which removed it from both the gaze position and the dock (Figure 3(b)).

The GazeCue and Gaze+Dock notifications were designed based on Ilo et al.'s [19] two key design principles (DP) for effective notification systems in immersive environments: DP1) avoid occlusion of important scene elements and DP2) easy noticeability without undue distraction as also mentioned by other studies [15, 11]. Regarding DP1, we dynamically positioned the notifications relative to the user's gaze—far enough (1 meter) to be noticeable but shifted to avoid overlapping task-relevant objects or cluttering the workspace. For example, when users looked downward, the notification's position was automatically adjusted to remain visible above the table surface. During pilot testing, we observed that if the user looked downward toward the table, the notification could become hidden. To address this, we adjusted the system to ensure that notifications appeared just above the table when such gaze directions occurred. Additionally, we ensured that even when the user looks toward the customer, the notification does not appear beyond the customer. Regarding DP2, we used natural gaze behavior to place notifications where users are already looking, increasing the chance of being noticed without relying on intrusive visual or auditory cues. The 3-second display time, determined through pilot testing, provided enough exposure for noticeability while minimizing distraction or fatigue.

4.3 Experimental Design & Evaluation Metrics

We designed a within subject study with 4 notification types (GazeCue, Gaze+Dock, onObject, onDock) resulting in 4 conditions. Conditions are counter-balanced across participants using Latin-square design to prevent any learning effect.

During the experiment, we recorded the following metrics. For clarity, these metrics are grouped into two categories: task performance and notification noticeability.

Performance Metrics:

Serving Time (s): The time taken by the participant to complete the serving a customer. It was measured from the moment the customer appeared until the participant successfully served the customer.

Serve Count (n): The total number of customers successfully served during each condition.

Notification Noticeability Metrics:

Reaction Time (s): The time between the onset of a notification and the moment the user noticed and clicked on it. It was calculated by subtracting the timestamp of the notification's display from the timestamp of the user's click.

Notification Click Count (n): The total number of notifications that the user noticed and clicked on. Each user click on a notification was counted as one occurrence.

Notification interactions were performed using pinch gestures via hand tracking, which was used throughout the entire study. In addition, we also included user experience evaluation questionnaires to better understand the usability of the notification types. We had the *System Usability Survey (SUS)*[4] to evaluate the usability. We also used the *NASA Task Load Index (TLX)*[17] to measure mental, physical, and temporal demand, as well as effort, frustration, and performance. Lastly, we included *Igroup Presence Questionnaire* (IPQ)[46] for the presence evaluation. Participants are asked to fill each questionnaire for each of the notification types.

At the end of the experiment, we asked participants to rate their mental and physical fatigue on a scale of 1-7 (1 being the lowest, 7 being the highest). Additionally, we asked them which notification type they would prefer most and why, as well as their last preference and the reasons. Moreover, we asked them to rank each notification type.

4.4 Participants

We recruited 16 participant (8 female, 8 male) from the local university with ages ranging between 19 to 30 (M= 23.81, SD= 2.81). 14 of them were right-handed, and the rest were left-handed. All participants reported corrected-to-normal vision. When asked about how many times they had experienced VR previously, one participant reported never, four reported 1-3 times, one reported 3-5 times, and 10 participants reported more than 5 times. Only four participants reported they had prior serving experience. None of them had used the ARtisan Bistro setup before.

4.5 Apparatus

We used a 13th Gen Intel(R) Core(TM) i9-13900KF at 5.8 GHz, 32 GB RAM desktop PC with an NVIDIA GeForce RTX 4070 graphics card. We used an Oculus Quest Pro HMD and Unity3D version 2022.3.47f1 to implement the virtual environment.

4.6 Procedure

After reading and signing the consent form, participants were instructed about each cooking task (burger, pizza, coffee) and the different notification types (GazeCue, Gaze+Dock, onObject, onDock). They were allowed to familiarize themselves with the cooking environment and the tasks before starting the experiment until they feel comfortable and ready. Before the experiment, we calibrated the eye tracking of HMD for each participant. Participants did the experiment in a 4x4 meters completely free environment to make sure they would not hit any real world object (Figure 1(a)). Participants were specifically instructed to click on the notifications as soon as they noticed them in the virtual scene (except for GazeCue, which automatically disappears after 3 seconds). In each condition, a total of 6 customer avatars visited the cooking station, with a maximum of 3 customers appearing simultaneously. After each condition, participants were asked to complete the System Usability Survey (SUS), NASA TLX, and Igroup Presence Questionnaire (IPQ) for each of the notification type. At the end of the experiment, participants completed the post-experiment questionnaires. In total, the experiment took about 30 minutes.

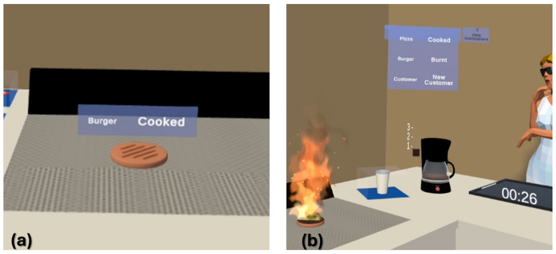


Figure 4: Visual Notifications: a) onObject: Notification is shown on the related object. b) onDock: Notifications are set to appear at a fixed position.

5 RESULTS

The data was pre-processed and plotted through JMP software. Data analysis was done using one-way repeated measures (RM) ANOVA using SPSS 28. The data was considered normally distributed if the Skewness (S) and Kurtosis (K) values were within ±1 [16, 31]. Otherwise, we used log-transform before ANOVA. If the data was not normally distributed even after the log transform, we used Aligned Rank Transformation (ART) [49] on the original data before ANOVA. We used the Bonferroni method for post-hoc analyses and applied Huynh-Feldt correction when $\varepsilon < 0.75$. For non-parametric data, we analyzed it using Friedman's ANOVA Test. The graphs shown in the figures show the mean, and the error bars show the standard error of the mean.

Serving time (S=0.09, K=-0.64) and reaction time (S=0.95 , K=0.02) data were normally distributed. For serving count, reaction count, and all questionnaire data, we applied the non-parametric Friedman's ANOVA test and its pairwise comparisons for post-hoc analyses.

5.1 Performance

Serving Time (s): According to Table 1, we found a significant main effect on serving time for notification types (F(3,45)=8.988, $p<0.001$, η^2=0.375). Participants served faster with GazeCue compared to onObject ($p<0.05$) and onDock ($p<0.001$) (5(a)).

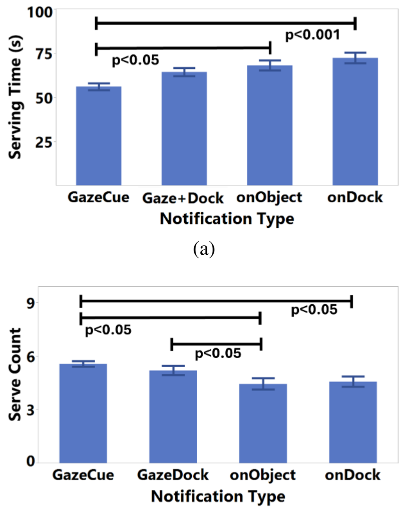
Serve Count (n): Based on Table 2, we found significant main effect on serve count for evaluated notification types ($\chi^2(3) = 14.79$, $p = 0.002$). Post-hoc results showed that participants served more customers with GazeCue than onObject ($p = 0.005$) and onDock ($p = 0.017$). Lastly, they served more customer while using Gaze+Dock than onObject ($p = 0.047$) (5(b)).

Table 1: Serving duration of participants for notification conditions.

Notification Types	Mean	SD	SEM
GazeCue	56.07	18.47	0.9
Gaze+Dock	64.34	20.44	2.24
onObject	68.1	24.24	2.87
onDock	72.36	26.13	3.05

Table 2: Average number of customers served for notification conditions.

Notification Types	Mean	SD	SEM
GazeCue	5.56	0.63	0.15
Gaze+Dock	5.18	1.04	0.26
onObject	4.43	1.26	0.32
onDock	4.56	1.15	0.28



(a)

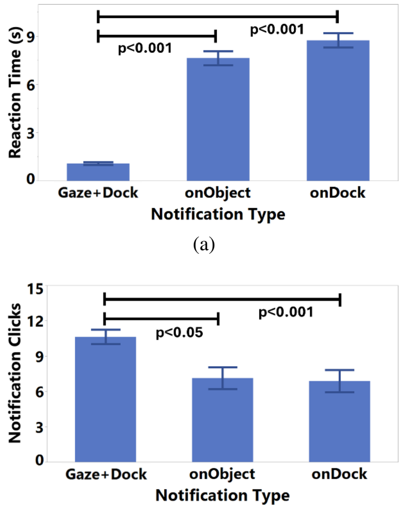
(b)

Figure 5: a) Serving time and b) Number of customers served successfully.

5.2 Notification Noticeability

Reaction Time (s): Our results in Table 3 showed that there is a significant main effect on reaction time for notification types (F(2,30)=41.010, p<0.001, η^2=0.732). Participants clicked on notifications faster while using Gaze+Dock than onObject (p<0.001) and than onDock (p<0.001)(6(a)).

Notification Clicks (n): Based on Table 4, we found significant main effect on the number of notification clicks on notification types ($\chi^2(2) = 16.32$, $p < 0.001$). Our further post-hoc analysis showed that participants reacted to more notifications while using Gaze+Dock than onObject (p=0.006) and than onDock (p<0.001) (6(b)).



(a)

(b)

Figure 6: Notification Noticeability results: a) Reaction time to the notifications and b) Number of noticed notifications. In GazeCue condition, since the notification disappears after 3 seconds, reaction time and notification clicks dependent variables were not collected.

Table 3: Average reaction time to the notifications in different notification types.

Notification Types	Mean	SD	SEM
Gaze+Dock	1.08	1.17	0.09
onObject	7.64	4.62	0.43
onDock	8.75	4.72	0.45

Table 4: Average number of notifications noticed by participants in different notification conditions.

Notification Types	Mean	SD	SEM
Gaze+Dock	10.62	2.44	0.61
onObject	7.12	3.70	0.92
onDock	6.87	3.77	0.94

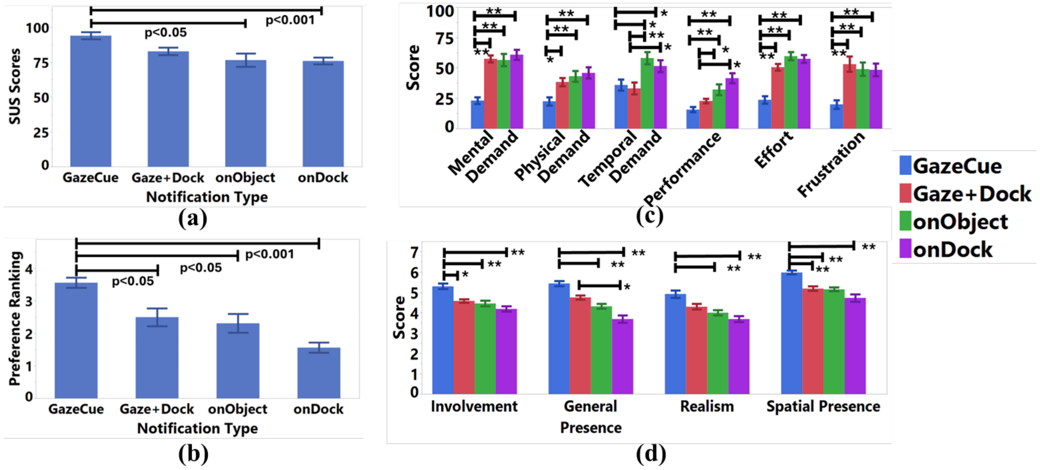
5.3 Questionnaire Results

After the experiment, we asked participants which notification type they would prefer most and why. Nine participants preferred GazeCue most, and P1 commented as *"With gaze notification was shown in front of me, leading to immediate understanding of the new status without any additional effort"* and P9 commented as *"I can easily notice other notifications while focusing on another task."*. Four of them preferred Gaze+Dock most, and P3 stated *"I liked being updated with the notifications in sight and also being able to go and check for them in a set place."* and P10 commented as *"I was able to see the notifications pop up no matter where I was looking, and I could double check in the dock."*. Lastly, three of the participants preferred onObject most, and P6 commented as *"It feels more intuitive. For example, if I'm really cooking a pizza, I would look at to the oven to see if it's ready. It works within the context."* and P5 commented as *"It was easy for me to manage everything."*.

We also asked participants which notification type they would prefer least and why. Five participants reported their last preference would be onObject notifications, and P3 commented: *"With object it was too much attention shift so I had to check multiple things and it takes longer time for me to see the notifications"*, and P13 reported as *"When I am focused on doing something I can't notice the notification for other things as they are on top of another object."*. Seven of them chose onDock as a last preference, and P8 commented as: *"It feels like the notification feature does not even exist since when multitasking (e.g. preparing pizza, burger, coffee), I would need to also focus on not missing notifications which actually makes it hard to coordinate between different tasks. I performed badly serving customers due to notifications appearing without my knowledge so I was missing them."*, and P16 commented as *"It is hard to track notifications on the dock, sometimes I totally forget to check there."*. Lastly, four of them reported their last preference would be Gaze+Dock, and P2 commented: *"Even though I don't miss notifications when I have both, sometimes it distracted me from the task as gaze notifications stay in front of me until I dismiss them."* and P12 commented as *"At some points distracting from the task at hand."*.

Participants ranked their order of preference at the end of the experiment (4 being the first choice, 1 being the last choice). Our results showed there is a significant effect on preference ranking for notification types ($\chi^2(3) = 19.19$, $p < 0.001$). Post-hoc analysis indicated that participants significantly preferred GazeCue over onObject (p=0.006), onDock (p<0.001) and Gaze+Dock (p=0.024) (Figure 7(b)).

Additionally, participants rated their overall mental and physical fatigue on a scale of 1-7 (1 being the lowest, 7 being the highest).



(a)

(b)

(c)

(d)

Figure 7: Subjective results: a) SUS scores. b) Preference Ranking across notification types. c) IPQ results for each sub-scale d) NASA TLX results for each sub-scale. ** indicates (p<0.001) and * indicates (p<0.05)

Participants did not report significant mental (M=2.62, SD=1.36) nor physical fatigue (M=2.12, SD=0.99).

Usability. As stated before, after each notification condition, participants filled the SUS questionnaire. The mean SUS scores and grades can be found in Table 5. Our results showed that there is a significant main effect on SUS scores for notification types ($\chi^2(3) = 20.12$, $p < 0.001$). Participants found GAZECUE is more usable than ONOBJECT (p<0.001) and than ONDOCK (p<0.05) (Figure 7(a)).

Table 5: SUS Analysis Results and Grades.

Notification Type	SUS Score (M)	SUS Grade
GazeCue	94.06	A (Excellent)
Gaze+Dock	82.81	A (Excellent)
onObject	76.56	B (Good)
onDock	75.93	B (Good)

Presence. We analyzed IPQ through four sub-scales as recommended [48]. IPQ was prepeared on a 1-7 scale and adjusted as 1 represents the lowest presence, 7 represents the highest. Mean, standart deviation, and standard error values of each sub-scale can be found in Table 7.

Our results showed that there is a significant main effect on Spatial Presence (SP) on notification types ($\chi^2(3) = 25.38$, $p < 0.001$). In our post-hoc analysis, we found that participants perceived more special presence using GAZECUE than ONOBJECT (p<0.001), than ONDOCK (p<0.001) and GAZE+DOCK (p<0.001). There is also a significant main effect on Involvement (Inv) results on notification types ($\chi^2(3) = 20.14$, $p < 0.001$). Participants felt more involved using GAZECUE than ONOBJECT (p<0.001), than ONDOCK (p<0.001) and than GAZE+DOCK (p=0.024). In terms of Realism (Real), we found a significant difference between notification types ($\chi^2(3) = 20.86$, $p < 0.001$). Participants had higher experienced realism while using GAZECUE (p<0.001) than ONOBJECT (p<0.001) and than ONDOCK (p<0.001). Lastly, we found significant main effect on General Presence (GP) scores for notification types ($\chi^2(3) = 32.65$, $p < 0.001$). Participants' overall presence was higher in GAZECUE than ONOBJECT (p<0.001) and than ONDOCK (p<0.001). Also, GP was found higher using GAZE+DOCK than ONDOCK (p=0.004) (Figure 7(c)).

Cognitive Load. We evaluated cognitive load through NASA TLX questionnaire for each notification type. We analyzed and reported Raw-NASA TLX scores. Mean and standard deviations for each sub-scale can be found in Table 6. We found significant main effect on *Mental Demand* ($\chi^2(3) = 28.79$, $p < 0.001$), *Physical Demand* ($\chi^2(3) = 15.85$, $p = 0.001$), *Temporal Demand* ($\chi^2(3) = 18.88$, $p = 0.001$), *Performance* ($\chi^2(3) = 22.01$, $p = 0.001$), *Effort* ($\chi^2(3) = 25.45$, $p = 0.001$) and *Frustration* ($\chi^2(3) = 22.88$, $p = 0.001$) scores on notification types.

Participants reported significantly less mental demand while using GAZECUE than other evaluated notifications ($p < 0.001$). Additionally, physical demand was significantly lower in GAZECUE than in ONOBJECT ($p < 0.001$), ONDOCK ($p < 0.001$) and GAZE+DOCK ($p = 0.04$). Participants had lower temporal workload while using GAZE+DOCK than ONDOCK ($p = 0.006$) and than ONOBJECT ($p < 0.001$). Additionally, they had less temporal workload with GAZECUE than ONOBJECT ($p = 0.003$) and ONDOCK ($p = 0.045$). Participants reported lower perceived performance workload in the GAZECUE than ONOBJECT and ONDOCK ($p < 0.001$). Similarly, GAZE+DOCK was rated lower than ONOBJECT ($p = 0.028$) and ONDOCK ($p = 0.008$), suggesting they felt more successful and satisfied with their task performance. In terms of Effort, participants reported that they had less workload and they were less frustrated with GAZECUE than other three notifications ($p < 0.001$) (Figure 7(d)).

6 DISCUSSION

In this paper, we investigated gaze-based notification designs in VR cooking task environment by evaluating GAZECUE and GAZE+DOCK notifications, which follow gaze direction. Previous research has highlighted the ongoing challenge of designing effective notification systems, as many existing approaches fail to address at least one of the key design considerations—noticeability, cognitive load, and presence [18, 45, 23, 44, 42, 19]. Our study aimed to fill this gap by investigating how gaze-based notifications affect user performance, noticeability, cognitive load, presence, and usability in dynamic VR tasks.

Our findings for *Performance* and *Noticeability*, supports our **H1** suggesting that gaze-based notifications improve user performance and notification noticeability in VR. Our results align with the previous studies [19, 29] results where they found that a gaze-aware approach for notification design improves noticeability. Similarly, our results support previous studies [18, 45, 37] which found that placing notifications within or near the user's active FoV to ensure

Table 6: Mean Raw-NASA TLX scores: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Performance (P), Effort (E), Frustration (F).

	MD	PD	TD	P	E	F
GazeCue	M=23.12 SD=11.08	M=22.5 SD=13.29	M=35.93 SD=17.81	M=15.63 SD=8.54	M=23.75 SD=12.31	M=20 SD=14.02
Gaze+Dock	M=57.5 SD=11.7	M=38.43 SD=13.13	M=33.12 SD=19.82	M=22.81 SD=7.74	M=50.63 SD=11.52	M=53.12 SD=24.82
onObject	M=56.56 SD=20.22	M=43.13 SD=17.59	M=58.12 SD=20.49	M=32.18 SD=17.51	M=59.68 SD=13.47	M=49.06 SD=22.52
onDock	M=60.93 SD=16.45	M=45.94 SD=18.46	M=51.56 SD=19.64	M=41.56 SD=16.3	M=57.5 SD=12.78	M=48.43 SD=21.11

Table 7: Mean of IPQ scores between Sub-Scales: Spatial Presence (SP), Involvement (INV), Experienced Realism (REAL), and General Presence (GP).

	SP	Inv	Real	GP
GazeCue	M=5.98 SD=0.37 SE=0.09	M=5.3 SD=0.56 SE=0.14	M=4.92 SD=0.72 SE=0.18	M=5.44 SD=0.51 SE=0.13
Gaze+Dock	M=5.18 SD=0.47 SE=0.11	M=4.58 SD=0.36 SE=0.09	M=4.29 SD=0.56 SE=0.14	M=4.75 SD=0.44 SE=0.11
onObject	M=5.15 SD=0.36 SE=0.09	M=4.45 SD=0.55 SE=0.13	M=4.0 SD=0.52 SE=0.13	M=4.31 SD=0.47 SE=0.11
onDock	M=4.72 SD=0.71 SE=0.17	M=4.18 SD=0.51 SE=0.12	M=3.68 SD=0.58 SE=0.14	M=3.69 SD=0.7 SE=0.18

they are noticed. Our study extends these results by showing that notifications following gaze direction improves noticeability. However, while our gaze-based notifications significantly improved task performance, these results do not align with earlier studies [19, 29]. We believe this discrepancy is primarily due to differences in notification and task design. For instance, Lu et al.[29] reported reduced effectiveness because their design imposed higher cognitive load—it required users to actively "control" the interface with their gaze to access information. Similarly, Ilo et al.[19] found no significant performance improvement, likely due to both task differences and notification placement, as their system displayed notifications at a fixed position in 3D space based on near gaze tendencies rather than at the precise gaze direction. Thus, while our results support **H1** by showing improvements in performance and noticeability, we argue that performance improvements from gaze-based notifications can be dependent on the task and notification design.

Subjective Feedback and *Usability* scores based on SUS evaluation indicate that GazeCue was significantly preferred over other notification types, supporting **H2**. P4 reported that *"Sometimes the object was not in my view, and I did not notice the notification, and for the dock, I missed the track notification panel. But with gaze, I could see the notifications directly."*. This highlights the importance of notification designs that can keep users informed where users frequently change focus and in time-sensitive tasks. GazeCue allowed them to stay focused without breaking immersion, whereas fixed-location notifications like onDock were harder to track and more easily missed—particularly during multitasking. onDock was the least preferred design, and seven of the participants reported that it was overwhelming to check a fixed place, and resulted the higher missing notification counts, which aligns with previous work's results [42]. Although Gaze+Dock improved performance and noticeability, its usability rating was lower than GazeCue. We attribute this to increased visual complexity: users had to process notifications at both their gaze point and in the dock. This added effort may explain why only 4 participants preferred this design despite its performance benefits.

Cognitive load results further support **H2**. GazeCue significantly reduced workload across all NASA-TLX sub-scales. In contrast, Gaze+Dock reduced temporal demand but increased frustration, likely due to the constant visual presence of the notifications at their gaze position. These findings are consistent with prior studies [18, 45], which found that persistent in-FoV notifications decrease user experience despite improving noticeability. Our results highlight the value of temporary gaze notifications like GazeCue, which appear only when needed and reduce cognitive load. GazeCue also scored highest in *Presence* measures. Participants found it more realistic and engaging compared to other designs, as it allowed them to remain focused on the environment and task without being overwhelmed. Gaze+Dock, while still outperforming it did not reach the same presence levels —again, likely due to the distraction of the visual complexity as it was introduced. These findings suggest that gaze-based notification designs can improve presence if designed carefully without increasing visual complexity.

These results suggest that gaze-based notification designs are promising, however, it should be carefully designed without overwhelming and distracting the user. Our results further extend previous work's findings in terms of notification designs are task dependent, meaning that as Hsieh et al. [18] suggested, *if the time is important, users need notifications in their FoV.* Building on this, our findings highlight that while gaze-based notifications are effective, the duration of their visibility must be carefully managed, as extended display times without appropriate dismissal mechanisms may increase cognitive load and hinder user experience.

Future studies can also investigate the integrating gaze-based notifications with other modalities, e.g., haptics or audio. Prior work [13] showed that haptic notifications can be hard to memorize and combining them with gaze may make them easier to understand and notice. Haptics can also act as a backup if gaze notifications are occluded or fail. Previous work also found that audio cues improve noticeability, which could also support gaze-based methods [42, 8].

6.1 Design Implications

Based on our findings, we propose the following design recommendations: **1) Use gaze-based notifications for time-critical tasks:** When rapid user response is essential, gaze-based placement ensures that important notifications appear within the user's focus area and are less likely to be missed. **2) Optimize notification duration:** Short display times are effective for simple alerts. However, excessively long durations may increase cognitive load. **Minimize visual overload:** Combining multiple notifications (e.g., gaze + dock) may improve performance but can also raise cognitive load. Balance visibility and simplicity to maintain usability.

7 LIMITATIONS

GAZECUE 's 3-second duration was optimized for this specific task context. Although this duration proved effective for time-sensitive interactions, different task types may require adjustments in visibility duration or dismissal mechanisms to balance noticeability and cognitive load.

Although GAZE+DOCK improved performance and noticeability, its increased visual complexity also raised cognitive load. This highlights the importance of carefully balancing visual prominence and simplicity. However, this trade-off was not explored systematically in our study and can be further investigated.

While our study was conducted in a controlled VR environment to isolate the effects of gaze-based attention, this limits the generalizability of our findings to more dynamic or uncontrolled settings. In particular, AR environments introduce additional distractions (e.g., moving people, lighting changes) that may interfere with gaze-based notification performance [7].

Even though our participant pool was gender balanced, the age range was limited, which may restrict the generalization of our findings. Future studies should consider a more diverse participant group to evaluate age-related differences.

Lastly, while our study focused on notifications for task-relevant, parallel ongoing events, such as food being ready or burning, we did not examine notifications related to unexpected or out-of-task events. It is possible that user responses, noticeability, or cognitive load may differ for such notifications. We consider this a limitation of our scope and an opportunity for future research.

8 CONCLUSION

In this paper we explored gaze-based notifications, GAZECUE and GAZE+DOCK by comparing with world-fixed visual notifications, ONOBJECT and ONDOCK in VR cooking task that we adapted from AR open source cooking task ARtisan Bistro where users engage cooking and serving customers. Our results showed that both GAZECUE and GAZE+DOCK had higher task performance and noticeability. Additionally, GAZECUE was the most preferred by participants and resulted significantly lower cognitive load while improving the user's sense of presence.

Our findings also highlight important considerations regarding the design of gaze-based notifications. While GAZE+DOCK improved noticeability and performance, it also led to increased user frustration. This was primarily due to its persistent presence in the user's field of view (FOV) until manually dismissed, which disrupted immersion and increased frustration. These results emphasize the importance of designing dynamic and non-intrusive gaze-based cues. For instance, pop-up style notifications such as GAZECUE, which appear and disappears after 3 seconds, offer a more efficient and immersive experience.

Overall, our findings suggest that gaze-based notifications hold strong potential for improving user interaction in VR. As future work, we plan to further investigate adaptive notification systems that personalize the timing and duration of gaze-based cues depending on different tasks. Additionally, integrating multimodal feedback (e.g., audio or haptic cues) could further improve noticeability without increasing cognitive load.

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