The Attention Kitchen: Comparing Modalities for Smart Home Notifications in a Cooking Scenario

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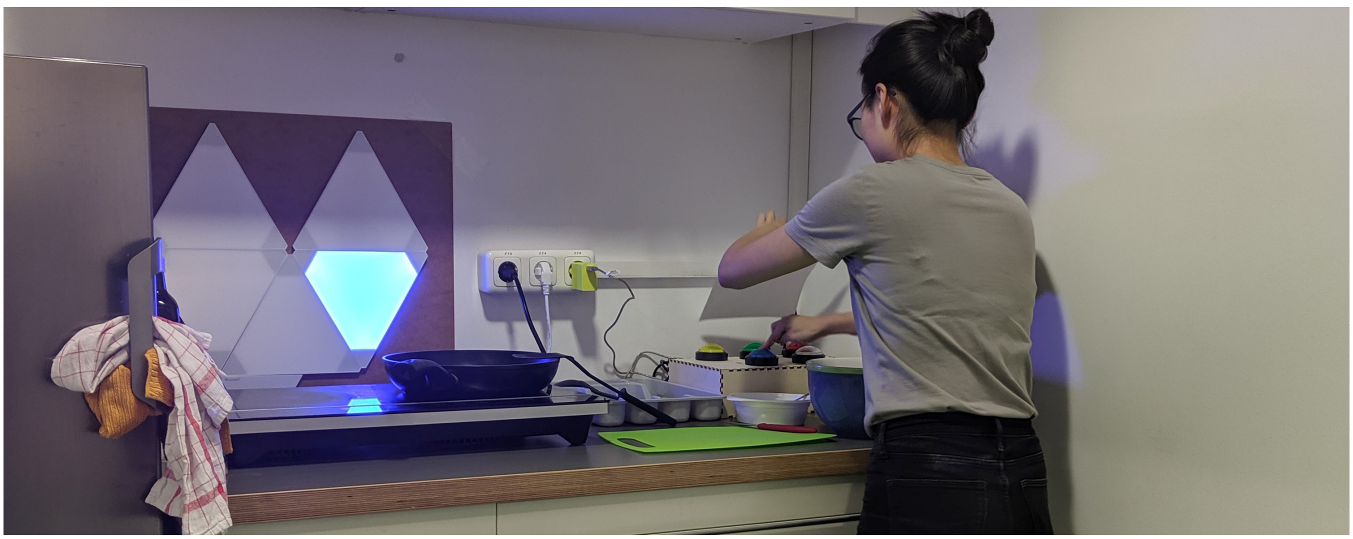

Figure 1: We conducted a study that evaluated three different notification modalities during a cooking session. Participants were asked to react on notifications that were displayed either *On-Object*, *On-Environment*, or *On-Smartphone*.

ABSTRACT

A steadily increasing number of notifications, auditory, visual or ambient, competes for the user's attention. Frequent unsuitable notifications can lead to a breakdown in efficiency and increase error rates. This paper compares the effectiveness, disruptiveness, and user experience of three different notification modalities: *On-Object*, ambient *On-Environment*, and *On-Smartphone* notifications. In a user study with 24 participants, we evaluate the three notification modalities during a cooking task where users were frequently exposed to notifications. Our results show that ambient *On-Environment* notifications minimize the time in which users can resume their primary task. Ambient *On-Environment* notifications were also perceived as least disrupting compared to the other two notification modalities. We discuss the design requirements for non-disruptive notifications in smart home environments and conclude with future strategies for notifying users at different urgency levels.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**.

KEYWORDS

Smart Home, Smart Kitchen, Notifications

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1 INTRODUCTION

Notifications permeate our everyday encounters with technology. For example, ubiquitous devices such as smartphones ask for our attention up to 63 times per day [19]. These notifications inform their users mainly about incoming social messages [20]. However, former work found that approximately 38% of the incoming notifications are considered as not essential and more than 50% as urgent from the users [32]. Furthermore, previous studies showed how many simultaneous notifications could be cognitively demanding and result in a negative user experience [2, 16]. Consequently, it remains challenging to design notification systems that empower users to attend to urgent tasks without causing disruptions.

Human-Computer Interaction (HCI) research attempted to improve notification by designing context- and task-specific ways of attracting users' attention when desired. Everyday mobile notifications were the subject of multiple studies [5, 12, 23]. Alternative approaches involved using ambient displays [23] or even interactive plants [27]. While researchers have developed many systems, there is still no consensus on exactly when particular notification strategies are most effective or how different notification designs compare performance and user experience. To address this challenge, this works builds on an earlier study [30] to explore the effectiveness and disruptiveness of different forms of notifications while the user is performing a primary task. We compare state-of-the-art *On-Smartphone* notifications with *On-Environment* notifications, and *On-Object* notifications in order to investigate the efficiency of perceiving notifications. Our work investigates the effective ways to display notifications during primary tasks, which require high attention from the user using cooking.

We implemented an interactive kitchen system which featured the three different notifications modalities *On-Object* (i.e., notifications displayed on an object), *On-Environment* (i.e., notifications are displayed using an ambient display), and *On-Smartphone* (i.e., notifications are displayed on a smartphone). Here, we conducted a study in which users were asked to respond to notifications delivered using the three modalities (see Figure 1). We found that receiving notifications on the smartphone required significantly more response time compared to the other two notification modalities, with *On-Environment* notifications resulting in the lowest reaction time. However, *On-Object* notifications required less task load and higher perceived usability compared to *On-Environment* notifications. Our results indicate how notifications can be embedded into intelligent environments and smart spaces to achieve high efficiency in scenarios where an important primary task is being performed. This paper contributes to studying the efficiency, usability, and task load produced by answering notifications using three notification modalities during a cooking task. Based on our results, we contribute insights on designing notification systems for usage scenarios where a highly demanding primary task is present.

2 RELATED WORK

Our work builds upon two research strands that have been researched in the past: (1) notifications in a smart home context and (2) smart kitchens.

2.1 Notifications in a Smart Home Context

Notifications are a crucial feature of current devices to inform users proactively of different kinds of information. With the smart home era, notifications informing the users about home information are getting more critical. An essential factor for home notifications is their social acceptance [17]. Vastenburg et al. investigated the acceptance of notifications conveying home information [25]. They showed that home notifications with high-urgent content are socially accepted, while notifications with medium-urgent content are socially accepted when displayed unobtrusively. In contrast, low-urgent notifications should be delayed until the urgency of the notification increases or never be shown to the users. Furthermore, since notifications are well known for causing disruptions or more error-prone performances [2, 11], it is essential to investigate whether different modalities to display incoming notifications affect disruptions or the users' performance according to a primary home task. Warnock et al. investigated whether using different cues to deliver the notifications to the users might affect the disruption or perception of the notifications [31]. First, they studied the perception of varying notification modalities during the execution of a typical home task (i.e., playing memory on a desktop screen) [31]. Then, they compared traditional notification mechanisms such as textual or pictorial representations presented on a desktop screen with novel modalities such as ambient visual displays in the users' periphery or olfactory displays. As a result of this, they found that the modality used to deliver notifications does not affect the performance of a conducted primary home tasks [30]. However, the modality affects the perception of the notification [31]. Further, Warnock et al. found that responding or ignoring an incoming notification does not affect the disruption effect according to the users' current primary task [31].

Other research investigated how notifications could be displayed in domestic environments [1, 5, 26, 27]. Czerwinski et al. suggested that notifications should be displayed subtly to support multiple devices without overwhelming the users [1]. Bourgeois et al. found that notifications should contain proactive suggestions to contextual control helps users in organizing their daily lives by microplanning and micro-scheduling household activities [5]. Voit et al. investigated different modalities to display notifications in a home context [26, 27]. In an online survey, Voit et al. studied the social acceptance of other modalities to show smart home notifications [26]. Here, they investigated the locations on-object (i.e., by displaying information on the device that generates the notification), on-display (i.e., by central display in the home environment), on-body (i.e., by using a display on the user's forearm) as well as on-smartphone (i.e., by receiving sending push notifications to the user's smartphone). In their comparison, Voit et al. found that receiving notifications on smartphones was the most accepted modality, followed by the locations on-object and on-environment. However, the on-smartphone modality was well known by their participants in contrast to the other investigated modalities. In a follow-up study, Voit et al. compared the modalities on-smartphone and on-object to display notifications in a long-term in-situ study [27]. Here, they studied how users experience notifications in a smart home context using a smart plant system. They found that the on-object modality was preferred as these notifications were more comfortable to perceive and more motivating to archive specific home tasks. Finally, Voit et al. suggested that notifications should be displayed within opportune moments with opportune modalities [27].

2.2 Smart Kitchens

Smart kitchens have recently become a relevant study domain. Here, cooking represents a real-world use case that includes actions that can be evaluated with assisting technologies. Scheible et al. conceptualized a smart kitchen [21] that uses several assistive systems to support cooking activities. However, the integration and evaluation of different notification modalities were not included within the presented research scope. Previous research focused on the development of smart kitchens for older adults. Blasco et al. evaluated how specific situations in kitchen environments can be simulated to study the implications for assistive technologies in these situations [3]. In this context, Kosch et al. [13, 15] looked into smart kitchens design for persons with cognitive impairments. By conducting a qualitative inquiry with tenants and supervisors of a sheltered living facility, the authors find relevant design principles for implementing smart kitchens for people with cognitive impairments. Based on these findings, a long-term study [14] was presented that shows the applicability and advantages of smart kitchens in sheltered living.

Other research domains focused on how calorie- and nutrition-aware contextual cooking plans can be provided [7, 8]. The authors showed how the users understand food components when displaying this information in a smart kitchen environment. Since recipes play a pivotal role during meal preparation procedures, Schneider [22] developed a "*Semantic Cookbook*". The "*Semantic Cookbook*" is a sharing system that allows users to share their recipes among other smart kitchens systems, effectively representing an integrated repository for recipes. The "*Semantic Cookbook*" is an approach that preserves knowledge about cooking procedures that can be easily shared with others. However, creating and recording content for digital recipes is still a cumbersome task. Therefore, Terrenghi et al. [24] developed a recording system for recipes. Cooking experiences can be recorded to be passed down to other users, demonstrate and practice cooking techniques, or practice specific cooking techniques. An evaluation of the system shows increased cooking motivation and an improvement in social communications during cooking. Bonanni et al. [4] evaluated different augmented reality interfaces for smart kitchens. The evaluation focuses on assistive components and their demand for attention and cognitive workload. Finally, Olivier et al. [18] presented a prototyping environment in which novel smart kitchen systems can be evaluated.

Previous research investigated the reaction times, usability, and task load of notifications in smart home environments. However, these notifications were investigated in static scenarios where users were not occupied with a primary task. As a result, different notification modalities were evaluated separately regarding reaction times, usability, and task load. We close this gap by presenting a study in which users are performing a cooking task as a primary task while being asked to react to the three different notification modalities *On-Object*, *On-Environment*, and *On-Smartphone*.

3 STUDY DESIGN

We conducted a study where the users' main task was cooking to understand the impact of different notification modalities in smart kitchens. In this paper, we use the study design created by Warnock et al. [30], but use different notification modalities and a more realistic primary home task. Here, we decided to investigate the suggested notification modalities *On-Smartphone*, *On-Environment*, and *On-object* by Voit et al. [26]. Further, we decided not to include auditory notifications, e.g., notifications delivered by smart speakers, since Voit et al. found that auditory notifications are perceived as annoying if they are not urgent [29]. Based on the results from former work, we derive the following hypotheses for our experiment:

- **H1:** The modality of notification will show a difference in reaction times (derived from Warnock et al. [30, 31])
- **H2:** The notification modality *On-Object* will score higher in terms of usability and task load than *On-Smartphone* (derived from Voit et al. [27])

3.1 Tasks

For our experiment, we asked the participants to accomplish two kinds of tasks: (1) cooking a meal (a typical primary home task) and (2) a secondary task where the participants had to respond to incoming notifications in parallel to the executed primary home task. We chose a cooking task in a kitchen environment as the primary task. Participants were instructed to cook Spaghetti Carbonara, which was also used in previous work [8]. The recipe consists of six steps: cooking Spaghetti noodles, preparing the sauce, and plating the final meal. The recipe was offered in a non-vegetarian and vegetarian variant. We ensured that the exchange of ingredients between both variants did not impact the overall cooking time or perception of notifications. Table 1 describes the recipe with the used ingredients.

For the secondary task, similarly to Warnock et al. [31], participants had to press a button in a specific color when they received an incoming notification. Here, the content of the notification informed the participants which of the five buttons should be pressed. The notifications were manually triggered by a researcher based on the action currently performed by the participant in the cooking task. However, the notification content, i.e., the button's color that should be pressed, was determined randomly. Table 2 shows the timings at which notifications were triggered during cooking.

3.2 Independent Variable

We define the *Notification Modality* as the only factor throughout the experiment. The *Notification Modalities* included three groups that we evaluated in a between-subject design. The condition in which the participant performed the task was chosen at random in three groups to balance the groups. This means that every participant received one of the following *Notification Modalities* during the experiment:

3.2.1 *On-Object.*

The buttons of the notification box can glow and indicate which button should be pressed. Thus, the notification box serves as a simulated object which was able to display notifications on the item itself (see Figure 2(a)).

Recipe for Spaghetti Carbonara:
1. Slice 40 g bacon into small strips.
2. Heat the oil in a deep skillet over a medium flame.
3. Add the bacon for about 3 minutes until it is crisp and the fat is rendered.
4. Cook 100g Spaghetti in a pot of boiling salted water until al dente.
5. While pasta is being cooked, beat together one egg, whipped crème (125ml), some cheese, bacon from step 1, and 1/4 teaspoon salt in a small bowl.
6. Drain Spaghetti in a colander and then pour egg mixture into the pasta in a pot, then toss over moderate heat to combine. Serve immediately.

Table 1: Steps of the recipe for Spaghetti Carbonara [7].

Pre-defined times for notifications:
1. Cut the bacon into small strips
2. Heat the oil in a deep pan over medium heat
3. Fry the bacon until it's crispy
4. Boil the water
5. Add Spaghetti to the pot with boiling salted water
6. Get a bowl
7. Measure whipped cream (315ml)
8. Add the bacon
9. Drain Spaghetti in a sieve
10. Mix with the tongs at moderate heat

Table 2: Steps in the cooking process that were used by the experimenter to manually trigger notifications.

3.2.2 On-Environment. We used five Nanoleaf panels to display ambient notifications on a central display in the environment. The Nanoleaf panels were mounted above the cooktop (see Figure 2(b)). As a result, one of the Nanoleaf panels was assigned to one of the buttons in the wooden box and glowed in the button's color to be pressed when a notification was triggered.

3.2.3 On-Smartphone. Notifications were displayed on a smartphone screen located next to the cooktop. The smartphone remained in the same position during the whole experiment. The smartphone triggered a loud notification sound when a notification arrived. The participants were asked to turn on the smartphone screen to read the notification, which told the participant which button should be pressed (see Figure 2(c)).

3.3 Measures

We utilized several measures to quantify the perceived task load, system usability, and efficiency. First, we operationalize the task load using the NASA Task Load Index (NASA-TLX) [9, 10]. Furthermore, we measured the perceived usability using the System Usability Scale (SUS) [6]. Finally, we assessed task performance efficiency in the secondary task by measuring the time difference between the moment the notification was presented and the user pressing the button.

3.4 Apparatus and Cooking Environment

We constructed a wooden box with five different buttons (see Figure 2(a)). Each button represents a different color. During specific cooking steps, notifications were manually triggered by the experimenter. The notification indicated the color of the button that should be pressed.

We use two NodeMCU with the ESP8266 microcontroller units[1] that are connected to a wireless network and the buttons in the wooden box. Each button press is registered and the difference between the trigger of the notification (i.e., *On-Object*, *On-Environment*, *On-Smartphone* notification) and the subsequent correct button press is logged. The buttons are powered using a 12-volt battery. One of the NodeMCU units was also connected to the Nanoleafs via WiFi (i.e., for the *On-Environment* notification modality). Further, one NodeMCU was connected to the internet to trigger notifications on the smartphone (i.e., for the *On-Smartphone* notification modality) using Google Firebase (see Figure 3).

We installed the devices in the kitchen. We placed the Nanoleafs above the cooktop and put the buttons and the Smartphone next to the cooktop. Wiese et al. [33] found that more than 50% keep their phone on the table when they are at home or in the office. We only prepared and enabled the notification modality that was assigned to the participant. The other notification modalities were disabled and hidden. The kitchen included a refrigerator, two hotplates, a sink, various cooking utensils, and tableware.

[1] https://github.com/nodemcu/nodemcu-firmware

3.5 Study Procedure

The participants were informed about the experiment and its structure. The participants provided informed consent and filled a questionnaire about their personal demographic information. We got an overview of influential factors (e.g., cooking experience and expertise). The participants received a recipe for Spaghetti Carbonara on paper. They were instructed to cook according to the instructions (see Table 1). from the recipe from Chi et al. [8]. In a between-subject study design, participants were then assigned to a notification modality. Finally, participants started with the cooking procedure.

To enable comparability between the task completion times, the experimenter triggered a notification on one of the notification modalities based on a set of pre-defined actions during cooking. This was done to ensure that the participants worked on the same steps in the cooking process and were at a similar distance to the notification box when receiving the notifications. The notification modality displayed a color that indicated which button on the wooden box should have been pressed. The notification disappeared as soon as the participant pressed the correct button. The time difference between the appearance of the notification and its confirmation was logged on a laptop to determine the reaction time. The color was randomly selected. Overall, ten notifications were triggered during each cooking session. After the cooking, the participants filled in the questionnaires (SUS, NASA-TLX). Participants were compensated with EUR 5 and the option of eating their self-made meal.

Figure 2: *Notification Modalities* evaluated in the study. Participants were instructed to either cook with (a) *On-Object*, (b) *On-Environment*, or (c) *On-Smartphone* notifications in a between-subject study design.

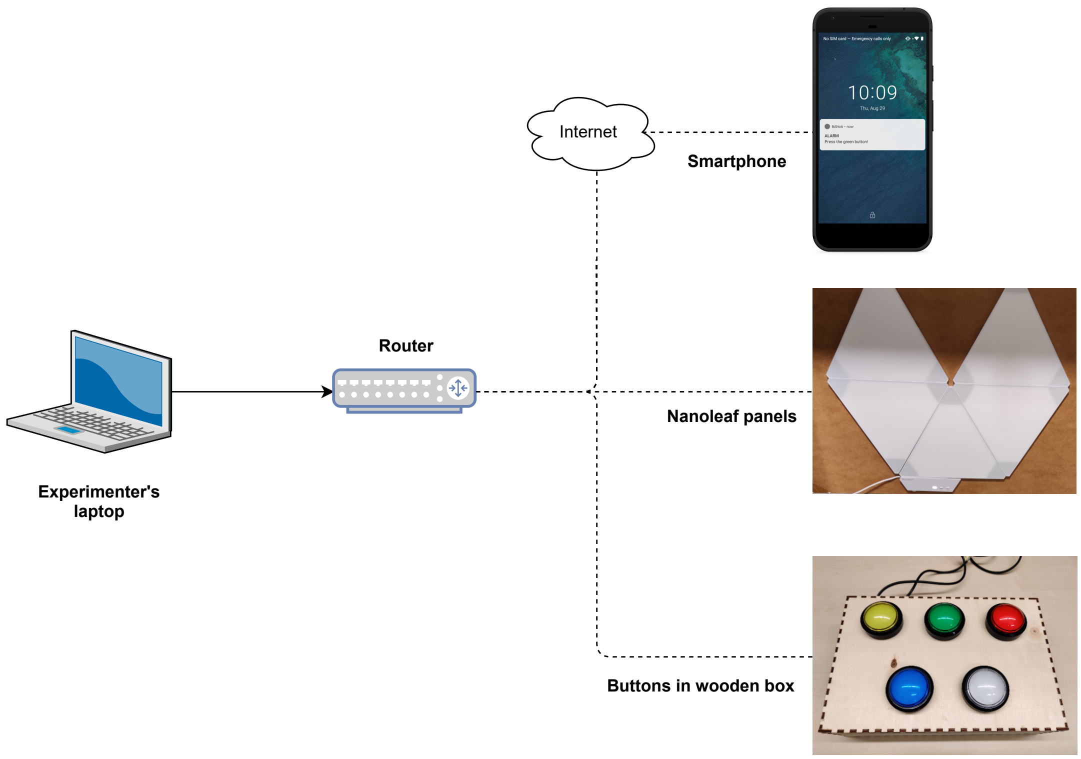
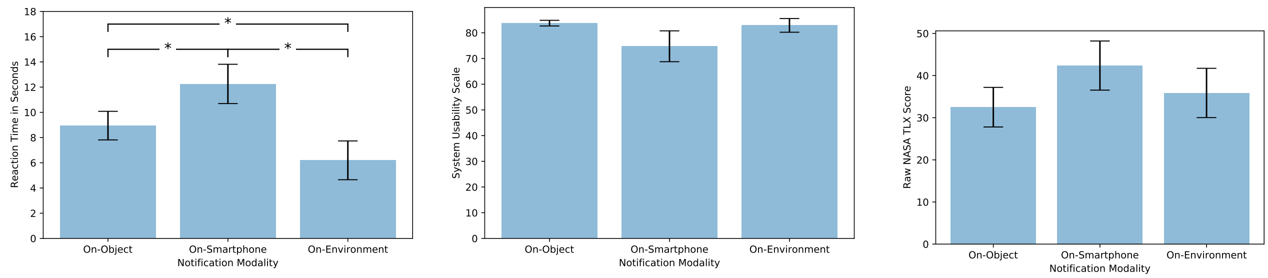


Figure 3: Architecture of the notification environment. Nanoleafs (i.e., *On-Environment*), a NodeMCU that is directly connected to the wooden button box (i.e., *On-Object*), and a smartphone (i.e., *On-Smartphone*) are connected with each other to trigger notifications that are confirmed by pressing the respective colored button on the wooden box.

4 RESULTS

We present the results of the study in the following. First, we specify our participant sample and present the statistical analysis of the data on the dependent variables. A Shapiro-Wilk was conducted on the measures to test for violations of normality. Second, we apply statistical testing to investigate our measures for significant differences. During the study, we observed that the participants responded with different strategies to an incoming notification. This concerned the notification being displayed while draining the Spaghetti in a sieve. One group of participants interrupted themselves during the task to respond to the incoming notification as fast as possible. In contrast, others ignored the notification to finish the task first. Since these different strategies directly affected the response time, we excluded the collected data for the step "draining the Spaghetti in a sieve" during the pouring process from the user data set in our analysis (see Table 2, step 9).



(a) Reaction time (b) System Usability Scale (SUS) (c) NASA-TLX

Figure 4: Averaged results of the study measures between the three notification modalities. (a): Mean reaction times as measure for efficiency, (b) system usability scale as assessment for usability, and (c) NASA-TLX scores as indicator for task load.

4.1 Participants

In total, 24 participants (5 female, 19 male) took part in our study. The group consisted of thirteen students, eight Ph.D. students, and three academic researchers. Participants were between 20 and 31 years old ($M = 25.625$, $SD = 3.25$). The participants rated their cooking experience as an average of $M = 4.75$ out of a seven Likert scale ($SD = 1.19$). Overall, eight participants were assigned randomly to each of the previously described notification modalities.

4.2 Reaction Times

Averaging the reaction times for each condition resulted in the lowest time in seconds for *On-Environment* notifications (M = 6.20, SD = 13.32), followed by *On-Object* notifications (M = 8.95, SD = 9.62) and *On-Smartphone* notifications (M = 12.25, SD = 13.31). Figure 4(a) depicts the mean reaction times per condition. A Shapiro-Wilk test revealed a violation of normality, $p < .05$. A Kruskal-Wallis test showed a significant main effect for the reaction times between the three groups, $\chi^2(2) = 57.64$, $p < .05$. A Bonferroni-corrected Dunn's test showed a significant difference between the conditions *On-Environment* and *On-Object*, *On-Environment* and *On-Smartphone* as well as *On-Object* and *On-Smartphone*, all $p < .05$.

4.3 System Usability Scale

The SUS yielded the highest averaged score for *On-Object* notifications (M = 83.75, SD = 3.11) followed by *On-Environment* notifications (M = 82.88, SD = 7.54) and *On-Smartphone* notifications (M = 74.75, SD = 16.98). Figure 4(b) depicts the mean reaction times per condition. A Shapiro-Wilk test did not reveal a violation of normality. A one-way ANOVA revealed no significant main effect for the SUS between the conditions, $F(2, 22) = 1.46$, $p = 0.26$.

4.4 NASA Task Load Index

The NASA-TLX showed that the *On-Object* notifications elicited the lowest averaged task load (M = 32.50, SD = 13.29) followed by *On-Environment* notifications (M = 35.88, SD = 16.54) and *On-Smartphone* notifications (M = 42.38, SD = 16.49). Figure 4(c) illustrates mean task load per condition. A Shapiro-Wilk test did not reveal a violation of normality. A one-way ANOVA reveals no significant main effect for the raw NASA-TLX scores between the conditions, $F(2, 22) = 0.73$, $p = 0.49$.

4.5 Participant Remarks

We asked participants about their preferred notification modalities and further comments. Several participants remarked that the ambient light of the *On-Environment* condition was visible just by turning it on:

> "*You even saw it when you stood with your back to it.*" (P2)
>
> "*That's nice, you can see it immediately.*" (P5)

One participant noticed that the glow of the ambient lights could be already perceived in the peripheral vision, hence leading to faster reaction times:

> "*I noticed when I poured out the water, it started to glow behind me.*" (P20)

Another participant mentioned that ambient *On-Environment* notifications could be used to deliver notifications that require immediate notice. However, ambient notifications can become annoying otherwise:

> "*I live with an open kitchen, and it would be useful when I'm not cooking but sitting on my couch. I can perceive the light on the wall, knowing that I left the stove or forgot to close the refrigerator. During the cooking, they disturb me. If I could react later, it would be fine.*" (P12)

On-Object notifications were criticized because of their stationary setting. Participants had to keep an eye out for new notifications:

> "*It's just visual, you always have to keep an eye on it, that's not so good.*" (P8)

One participant proposed a multimodal approach for *On-Object* notifications. The addition of sound has the potential to increase the awareness of new notifications:

> "*The buttons could have made a sound.*" (P6)

Finally, participants justified their low preference for *On-Smartphone* notifications because it was unclear if incoming notifications would inform participants about the kitchen or other arbitrary notifications:

> "*Depending on the notification, I don't care [...], and then I have to pick up my mobile phone?*" (P9)

Finally, a participant remarked their dislike of touching the smartphone while cooking for hygienic reasons:

> "*Now it is already filthy.*" (P10)

5 DISCUSSION

How do different notification modalities influence the cooking performance and user experience in smart kitchen environments? We conducted a cooking study in which we compared the reaction times, usability, and task load of the three different notification modalities *On-Object*, *On-Environment*, and *On-Smartphone* to answer this question. We discuss the implications of our results in the following.

5.1 Impact of Notifications Modalities on Reaction Times, Usability, and Task Load

Our work confirms the results obtained in previous research. Warnock et al. [31] showed that ambient *On-Environment* notifications had a positive influence on the reaction times. Ambient notifications can be perceived through peripheral vision, hence making it easier to notice notifications. Therefore, our results confirm **H1**. Displaying notifications *on-object* was preferred in terms of usability and task load over the other notification modalities. This is in line with previous research by Voit et al. [27], where users preferred notifications to be displayed on a smart assistant itself rather than on a secondary screen (i.e., on a smartphone). In our study, the *On-Smartphone* condition required direct interaction with the smartphone (i.e., unlocking the screen, reading the notification, and confirming the notification), which we held responsible for longer reaction times and lower usability measures. Hence, our results are analogous to previous research investigating notification modalities in other smart home use cases. While we find a descriptive difference favoring *On-Object* notifications, we can not show a significant difference in our measures. Therefore, we do not confirm **H2**. Our results show that these concepts can be translated to other use cases, such as smart kitchens. We are confident that the presented notification designs can be utilized for different intelligent home environments.

5.2 Use the Right Notification Modality for the Right Job

On-Environment notifications showed a significant improvement in reaction times compared to *On-Object* and *On-Smartphone* notifications. However, *On-Environment* notifications are affected by a trade-off of lower usability and increase in task load compared to *On-Object* notifications. Time is a critical factor for specific cooking steps. Hence ***On-Environment* notifications are the preferred modality during cooking steps that require the user's immediate attention**. At the same time, our results show that *On-Object* notifications have proven to be superior in terms of usability and task load as confirmed by previous research [27, 31]. Hence, **designers should utilize *On-Object* notifications if events have a medium or low priority to maintain a positive user experience.** Finally, we acknowledge that the *On-Environment* and *On-Object* notification modalities are bound to the users' location. **The *On-Smartphone* notification modality can be used as an alternative way of delivering urgent notifications if the user is not near enough to the notification device to perceive the notifications**. However, *On-Environment* notifications using ambient lighting are limited to conveying simple information that can be interpreted by the users [28]. We are confident that these findings will guide designers of notification systems to implement the right modality depending on the usage context and scenario.

5.3 Limitations and Future Work

We acknowledge that our study was prone to several limitations. The presented research does not investigate how multimodal notifications could change the perception of notifications. In future work, we will explore if the combination of notification modalities influences reaction times and usability. This proposed study can reveal which notifications draw the initial attention towards a newly displayed notification. We also acknowledge that the research was conducted within a single kitchen room, where notifications were immediately noticed after appearance. If our results apply to a larger, walkable smart home with different rooms, it is subject to future work. Here, we plan a long-term study that deploys the investigated notification modalities by connecting our study prototype with a smart home device that regularly delivers notifications (e.g., a voice assistant or smart TV). This study will provide further insights into how users react to different notification modalities in the long term.

6 CONCLUSION

In this paper, we presented a study, which build on past work by from Warnock et al. [30] and compared the three notification modalities *On-Object*, *On-Environment*, and *On-Smartphone*. Our results reveal trade-offs between the notification modalities, where designers must prioritize the notification urgency, usability, and user mobility. Depending on the priority, smart kitchen environments need to deliver the right notification modality to the user to be noticed and avoid user experience mismatches. As smart environments will integrate notifications into more and more household devices and ambient living environments, our results guide designers in choosing the optimal modality for their use case. We are confident that our results inspire further investigation of notification systems in the home. We are confident about designing human-centered smart homes that use different notification modalities and provide an optimal user experience to enjoy their favorite home activities.

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