Pandemic Displays: Considering Hygiene on Public Touchscreens in the Post-Pandemic Era

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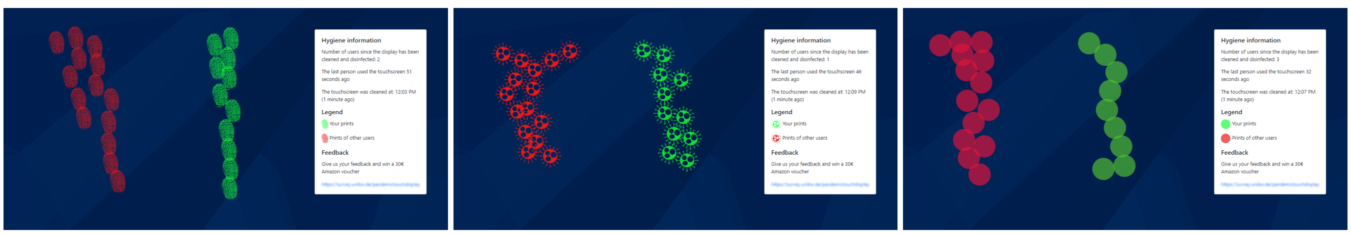

Figure 1: We investigated hygiene-related information on public touchscreens, first in an online survey and then with a prototype application. Our prototype, A) displays a panel showing hygiene-related information, and B) visualizes the exact points where prior users have touched on the screen. We experimented with three visualizations of touches: representations of fingerprints (left), viruses (middle), and circles (right). The fingerprints were rated most favorably.

ABSTRACT

The COVID-19 pandemic created unprecedented questions for touch-based public displays regarding hygiene, risks, and general awareness. We study how people perceive and consider hygiene on shared touchscreens, and how touchscreens could be improved through hygiene-related functions. First, we report the results from an online survey (n = 286). Second, we present a hygiene concept for touchscreens that visualizes prior touches and provides information about the cleaning of the display and number of prior users. Third, we report the feedback for our hygiene concept from 77 participants. We find that there is demand for improved awareness of public displays' hygiene status, especially among those with stronger concerns about COVID-19. A particularly desired detail is when the display has been cleaned. For visualizing prior touches, fingerprints worked best. We present further considerations for designing for hygiene on public displays.

CCS CONCEPTS

• **Human-centered computing** → **Touch screens**; **Empirical studies in HCI**.

KEYWORDS

Public displays, Hygiene, Pandemic, Touch interaction, COVID-19

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1 INTRODUCTION

Public interactive displays (PIDs) are numerous in urban areas. They appear in many public and semi-public locations and serve many functions, ranging from entertainment and information (e.g., map and store information at a shopping mall) to various services (e.g., withdrawing cash, buying train tickets, ordering and paying at fast-food restaurants). The overwhelming majority of public interactive displays work by *touching* them [7]. Touch is the prevailing approach for good reason, as touch interaction is directly accessible, fast, easy, and familiar [6, 24, 27, 34]. Touch displays are also generally more stable and less error-prone than installations using more complex hardware [16, 35].

Much of prior research has focused on *maximizing the usage* of public displays. This included studying how the space and location affect the display's visibility [3, 17, 18, 23, 48, 52], how passersby can be attracted to and kept engaged with the display [10, 13, 15, 30, 37, 38, 47], and how social situations affect the interaction [3, 40, 49, 55]. However, the recent COVID-19 pandemic introduced entirely new questions for public displays. Now, more than ever, we need to consider the possible costs of heavy use of shared touchscreens.

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Touching surfaces that have been touched by others may transmit bacteria [19] and carry the risk of infection [21].

To the best of our knowledge, questions regarding hygiene on public touchscreens have not been sufficiently covered by existing research in human-computer interaction (HCI). Touchscreens also provide creative opportunities in this context since all touches can be stored and then visualized back to potential future users, so they can avoid crowded areas on the screen. Investigating such visualizations is an important part of this work, since we currently do not know how they would affects users.

Therefore, in this work, we seek to understand how people perceive public touch displays during and after the pandemic, and whether there is value in providing users with hygiene-related information on public displays. *Our aim is to enable potential users to make a more informed choice about whether or not to interact with a public touchscreen.* Our main research questions are:

- **RQ1:** How do people perceive and consider hygiene on public displays, and how has COVID-19 affected them?
- **RQ2:** What kind of hygiene information do people want to see on public touch displays before use?
- **RQ3:** How do people feel about seeing the touches of prior users on touchscreens, and what is the most preferred design for such visualizations?

To answer these questions, we first conducted an online survey (n = 286), asking people about their perception and usage habits of various touchscreens in public spaces, and gathering initial responses to seeing hygiene-related information on public displays. Next, we created a public display prototype that visualizes the touches of past users and displays other hygiene-related information (Figure 1). We experimented with three visualizations of touches: fingerprints, viruses, and circles. We deployed the prototype in three locations for four weeks. We also distributed the prototype remotely as a web link, so that we could offer a safe way to provide feedback, especially for those who currently avoid leaving their homes. We linked a feedback questionnaire to the display prototype with a direct web link and a QR code. We collected 77 complete responses.

We learned that there is demand for increased awareness of hygiene on public touchscreens, particularly among those who reported strong concerns regarding COVID-19 in general. The most critical piece of hygiene information, as reported by our participants in both studies, was *when the display was last cleaned / disinfected.* As such, we recommend display owners to consider implementing mechanisms to display how much time has passed since the last cleanup. Other hygiene measures were also desired, including how many people have touched the display since the last cleanup, how much time has passed since the previous user, and where exactly on the screen other people have touched. Out of our three tested touch visualizations, fingerprints were strongly preferred. Their direct affordance to touch makes them immediately understandable, while remaining neutral in nature. Circles were largely seen as too abstract, making their function unclear. Viruses on the other hand, were seen as an overkill, even as fear mongering. All in all, these results suggest that even though there is generally demand for increased hygiene information, touchscreens should remain neutral about hygiene, thereby supporting the users' autonomy in deciding whether to touch the display.

Through this work, we provide a detailed discussion on and suggestions for how to handle hygiene on public touchscreens. We offer direct actionables and describe how these functions can be implemented. Furthermore, we identify directions for future work in this area, including a long-term investigation of the impact of hygiene information on the displays' usage and users' behavior.

2 BACKGROUND AND RELATED WORK

In this section, we discuss two topics that are important for this work. First, we look at the possibilities for public display interaction and discuss why touch interaction is the preferred method for many situations — and hence, why we should address matters of hygiene when using shared touchscreens. Second, we take a brief look at the risks of touch interaction and what we know from existing research about hygiene regarding public interactive displays.

2.1 Interaction with Public Displays

Besides touch interaction, many novel ways of interaction with public displays have been proposed – also such that do not require touching a shared screen. These methods include, among others, mid-air gestures and bodied interaction [1, 4, 31, 33, 41, 56], gaze interaction [26, 27, 34], speech interfaces [20], and using a personal device like a smartphone [9, 11, 14, 42], smartwatch [42], or augmented reality device [42] to control the display.

Many of the proposed methods above are successful in their own right and offer unique benefits. They also avoid the possible hygiene concerns for public displays, as they do not require touching the display. However, there are clear reasons why touch displays are overwhelmingly the most popular form of public interactive displays. Touch interaction is accessible, easy, and familiar [6, 24, 27, 34], and touch displays also tend to be significantly more stable and less error prone than many competing methods [35]. Furthermore, more unusual ways of interaction tend to be particularly challenging in public spaces, as potential users may fear looking foolish [10, 50], or they might have other concerns that prevent them from using the display [43]. Consequently, touch interaction is often the most preferred method in comparative studies [6, 27, 34].

There are also other methods for touchless interaction. Especially, QR codes allow for the extraction of information (e.g., a website URL) by scanning codes using a smartphone [6]. Due to the COVID-19 pandemic, we have seen QR codes emerge as a hygienic alternative in many daily situations, such as scanning a code for a restaurant's menu instead of using paper menus. However, QR codes offer very limited interaction opportunities and they are often not suitable for serendipitous or explorative interactions with public displays, as users need to pull out their smartphone, open the camera app, and scan the QR code [34].

In summary, despite a variety of other interaction methods, touch interaction is critical to public interactive displays. Therefore, in the wake of the COVID-19 pandemic, we must consider hygiene on public displays and the possible risks of using them.

2.2 Touching Public Screens: Hygiene & Risks

To our knowledge, hygiene has only appeared as a side note in some user studies on public displays [45]. Some participants have mentioned hygiene either as a downside of touch interaction, or as an upside of touchless interaction [27, 29, 34]. However, investigations specifically targeting hygiene on public displays are missing. In this work, we begin to address this critical gap. We look not only into current and past perceptions of hygiene on public displays, but also into possible solutions to improve hygiene and hygiene-related awareness. In this context, there are many opportunities as we can track the screen's touches and formulate potentially useful information back to future users. This can include things like how many different people have touched the screen and when, and also where exactly on the screen prior users have touched.

We should note that this is not a medical paper on COVID-19. Yet, we know from existing research that COVID-19 can spread via touch [21]. The likelihood of contracting COVID-19 in this way is relatively low compared to, e.g., airborne particles. However, we take a strong stand here that when it comes to matters of health and saving lives, even small improvements are considerable. Additionally, many aspects of our work are not specific to COVID-19, but rather deal with providing information about hygiene for touch displays more generally. Shared touchscreens can also contain bacteria [19]. Furthermore, other infectious diseases may appear in the future that can be transmitted from shared surfaces more easily, and our research will be valuable in such events. Finally, we imagine that the COVID-19 pandemic may have changed the public attitudes on hygiene for a long time or even permanently; people might now be more aware of hygiene and where they touch while in public, thereby changing the requirements for public touchscreens.

We also want to highlight that, aside from offering the benefit of health and saved lives, we are also concerned with giving people a more informed *choice*. By making passersby more aware of a public display's touch history, potential users can individually assess what the risks are and whether they want to touch the display.

3 RESEARCH APPROACH

To answer our research questions, we conducted two studies. Our research was conducted in the spring and summer of 2021. This situates roughly at the end of the so-called "third wave" and between the third and fourth wave of the COVID-19 pandemic. First, we distributed an online survey (n = 286) to investigate how the COVID-19 pandemic has affected the usage and perceptions of touch displays in public. Additionally, we inquired about what type of hygiene information people might want to see on shared touchscreens. Second, we developed a hygiene concept for public touchscreens, which implemented the hygiene functions that we initially inquired about in the survey. We deployed the hygiene concept in three locations, and distributed it remotely online. In this way, we gathered feedback from 77 users. In the next section, we will describe our online survey and its results. In the subsequent section, we will describe our public display prototype, its deployment, and the results.

4 ONLINE SURVEY

We conducted an online survey to better understand how people perceive and consider hygiene on public touchscreens, and how the COVID-19 pandemic has potentially changed these considerations. Even though our focus was on public, shared touchscreens, we also included questions about private touchscreen use (e.g., smartphones), to understand how perceptions of public touchscreens situate in the bigger picture.

We used SoSci, a survey tool installed on our institution's web server. Hence, the collected data was not handled or stored by any external parties. We distributed the survey via different channels, including Prolific, mailing lists, and social media. We reimbursed Prolific users through Prolific's reimbursement system. Participants who did not want to use Prolific, had the option to participate in a raffle of three 30 EUR vouchers by providing their email address.

4.1 Survey Content and Questions

Our survey consisted of the following aspects:

Demographics We asked the participants to report their age, gender, current country of residence, and occupation.

Frequency of use before/during the pandemic We asked how frequently participants used various touchscreen devices in public before the pandemic, and whether the frequency and way of use had changed since the pandemic began. The list of devices included personal smartphones (when used outside or in public spaces with other people), ATMs, ticket vending machines, information touch displays (e.g., display for food orders, informational maps), and entertainment touch displays (e.g., quiz games on a display in a museum).
The frequency of use before the pandemic served as a baseline for each participant. For this, we used an 8-point scale. This was because frequency of use can vary dramatically between people as well as between devices, thus several options were needed to provide a sufficiently accurate anchor point for each participant. For possible changes in frequency during the pandemic, participants used a 5-point scale to determine the extent of the change (from "strongly decreased" to "strongly increased").

Hygiene measures with public and private touch displays Participants responded to statements for both public touchscreens and private touchscreens on a 5-point Likert scale, regarding the hygiene measures they might take before, during, and after use (e.g., washing hands, minimizing touches).

Hygiene information on public touchscreens Participants responded to a set of statements on a 5-point Likert scale about whether they saw a link between COVID-19 and public touchscreens, and what kinds of hygiene information they would like to see on public touchscreens. Participants were also provided with an open text field to type whatever concerns or suggestions they had for public touchscreens.

Concerns regarding COVID-19 Finally, participants responded to four statements on a 5-point Likert scale regarding how concerned they were about COVID-19 generally. This way, we could contrast potential concerns regarding touchscreens to the participants' overall concerns about COVID-19.

4.2 Results

In total, we received 286 responses. 200 came from Prolific, while 86 were recruited via mailings lists and social media.

4.2.1 *Demographics.*
Our respondents consisted of 154 men (53.8%), 126 women (44.1%), and three non-binary persons (1.0%); three persons did not disclose their gender. The subjects were between 18 and 68 years of age, with an average age of 26 years (*SD*=8.51). Slightly over half of them were students (159, 55.6%), 111 (38.8%) were professionals in various fields, and 16 (5.6%) were unemployed. The respondents lived in various countries, the most popular being Germany (65, 22.7%), United Kingdom (61, 21.3%), the United States (42, 14.7%), South Africa (22, 7.7%), Australia (17, 5.9%), Portugal (13, 4.5%), and Poland (11, 3.8%). The remaining 55 respondents (19.2%) came in small proportions from other countries.

4.2.2 *Frequency of Touchscreen Interaction Before and During the Pandemic.*
Subjects reported their frequency of use of different displays in public before the COVID-19 pandemic, using an 8-point scale from "never" to "several times a day". The subjects used their smartphones several times a day (*Md*=8), ATMs and information touch displays once a month (*Md*=3), and ticket vending machines and entertainment touch displays less than once a month (*Md*=2).

Subsequently, the subjects were asked how their frequency of use changed during the pandemic on a 5-point scale from "strongly decreased" to "strongly increased". Generally, participants reported using their smartphones and information touch displays just as frequently (*Md*=3). The frequency of use for ATMs, ticket vending machines, and entertainment displays decreased slightly (*Md*=2).

4.2.3 *Hygiene Measures with Public and Private Touch Displays.*
Participants answered the same statements for both private and public touchscreens about potential hygiene measures they take prior to, during, and after use. A Wilcoxon Signed-Rank test revealed statistically significant differences between public and private touchscreens in all statements.

The subjects reported paying more attention to the hygiene of public touchscreens (Z=10.09, p=.00), even though both scored a median of 4. Subjects were also more active in avoiding touching public touchscreens (*Md* = 4) in contrast to private screens (*Md* = 2, Z=11.53, p=.00).

The respondents also reported that they disinfect their hands more often before (*Md* = 3, Z=8.25, p=.00) and after (*Md* = 4, Z=11.44, p=.00) the use of public screens in contrast to private ones (*Md* = 2, *Md* = 3). Similarly, subjects were more likely to wash their hands before (*Md* = 3, Z=2.23, p=.03) and after (*Md* = 4, Z=9.60, p=.00) using public screens compared to private screens (*Md* = 2, *Md* = 3).

Gloves were also used significantly more often when using public touchscreens than private screens (Z=3.85, p=.00). However, both scored a median of 1, suggesting that using gloves for hygiene reasons was extremely rare. Finally, individuals were significantly more likely to use unconventional techniques, such as pressing buttons using their knuckles, when using public displays (Md = 3) in opposition to private screens (Md = 2, Z=10.54, p=.00).

4.2.4 *Hygiene Information on Public Touchscreens.*
Participants rated statements regarding how much they would want to see specific types of hygiene information on public touchscreens (Figure 2). Participants also answered whether they believed that touching public displays increases the risk of contracting COVID-19, and the majority agreed (*Md*= 4).

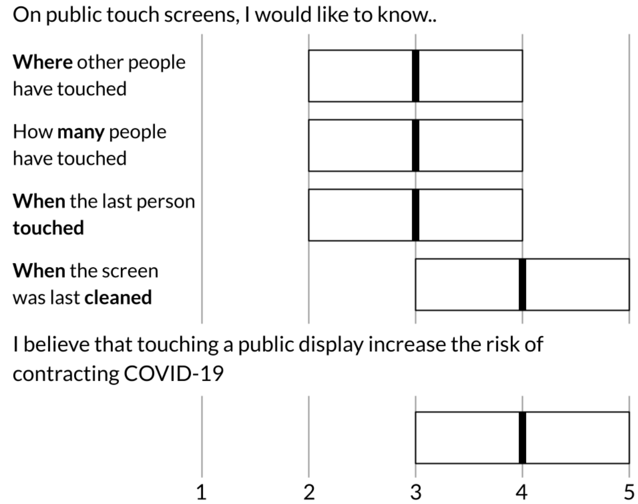

Figure 2: Participants stated whether they would like to see the four kinds of hygiene information on public screens. Also, they stated whether they believed that touching public displays increases the risk of contracting COVID-19. The statements were on a 5-point scale, where 1 = strongly disagree, 5 = strongly agree. The thick, black lines represent the medians, and the boxes represent the inner quartiles.

The respondents were generally neutral towards three types of hygiene information: where on the display the people before them have touched (*Md*=3), how many people have touched the display since the last cleaning (*Md*=3), and how much time has passed since the last person touched the display (*Md*=3). However, it was important to the participants to know how much time has passed since the display was last cleaned (*Md*=4).

A Wilcoxon Signed-Rank test revealed that subjects significantly preferred to see how much time has passed since the last cleaning, as opposed to how much time has passed since another person last touched the screen (Z=5.22, p=.00) or where the previous person touched the screen (Z=5.55, p=.00). Furthermore, the indication of how many people had touched the display before was significantly more preferred than the indication of where on the screen touches had been made (Z=5.34, p=.00) or how much time had passed since the last touch (Z=4.12, p=.00).

Additionally, a Spearman's correlation test showed a significant positive correlation between the belief that touching a public touch display increases the risk of contracting COVID-19, and all four hygiene functionalities: when the display was last cleaned ($r(284)$=.45, p=.00), how many people have touched the display before them ($r(284)$=.36, p=.00), where the person before them touched the display ($r(284)$=.37, p=.00), and how much time has passed since the last touch ($r(284)$=.38, p=.00). Hence, the stronger the person's belief that the risks of touching a public display, the more likely they are to want hygiene information on public displays.

4.2.5 *Concerns regarding COVID-19.*
The subjects also answered statements regarding their concerns about the COVID-19 pandemic in general. The majority of subjects were concerned about the

Table 1: Correlation between concerns about COVID-19 and and the desire to see hygiene information on public touchscreens. In the correlation matrix, A–D represent the concern statements, and 1–4 represent the hygiene statements.

COVID-19 Concern Statements	Hygiene Information Statements
A: I am concerned about the health risks that COVID-19 poses to me if I were to contract it	**1:** I would like to know where on the screen other people have touched
B: I am concerned about the health risks that COVID-19 poses to my close friends and family if they were to contract it	**2:** I would like to know how many people have touched the screen
C: I actively monitor how the COVID-19 pandemic develops in my area or country	**3:** I would like to know how much time has passed since someone else touched the screen
D: I actively monitor how the COVID-19 pandemic develops globally	**4:** I would like to know how much time has passed since the screen was last cleaned.

Correlation

	1	**2**	**3**	**4**
A	**Yes** r(284)=.23, p=.00	**Yes** r(284)=.24, p=.00	**Yes** r(284)=.20, p=.00	**Yes** r(284)=.25, p=.00
B	**Yes** r(284)=.13, p=.03	**Yes** r(284)=.18, p=.00	**Yes** r(284)=.12, p=.04	**Yes** r(284)=.22, p=.00
C	No p>.05	No p>.05	**Yes** r(284)=.16, p=.00	**Yes** r(284)=.17, p=.00
D	**Yes** r(284)=.13, p=.03	No p>.05	**Yes** r(284)=.13, p=.03	**Yes** r(284)=.13, p=.03

health risks of COVID-19 if they were to contract it (*Md*=4). Also, the respondents strongly agreed that they were concerned about the health risks that COVID-19 poses to their friends and family (*Md*=5). Lastly, the majority of subjects indicated that they actively monitor how the COVID-19 pandemic develops both regionally (*Md*=4) and globally (*Md*=4).

4.2.6 Correlation between COVID-19 Concerns and Demand for Hygiene Information. Finally, we calculated a Spearman's correlation to see if there was a link between COVID-19 concerns and the demand for hygiene information on public touchscreens (Table 1). There were four statements on both sides, resulting in 16 comparisons. Our analysis reveals a positive correlation in 13 of the 16 possible pairs, suggesting a very strong correlation overall.

4.3 Summary and Discussion

From the results, we can infer several interesting findings. First, participants report no changes or only a slight decrease in interaction in public during the COVID-19 pandemic. According to their self-assessment, they used their private smartphone in public just as much as before, as they did information displays. The use of ATMs, ticket machines, and entertainment displays decreased slightly. This would suggest that some participants did seek alternative ways, like online tickets, to avoid interaction with public technology. The decrease in the use of entertainment touch displays might be better explained by the COVID-19 regulations overall, as such displays are often found in locations such as museums. These locations were closed during much of the pandemic, or in cases they were open, would often have shut down these kinds of displays.

Second, respondents reported stronger hygiene measures when interacting with public displays than private displays. They also reported paying more attention to hygiene on public displays, and more frequently reported avoiding the use of public touchscreens. This suggests that overall there is some level of awareness of hygiene on public touchscreens, and that people are willing to think about their use. That said, it is notable that the majority of respondents were still relatively neutral about such measures, as almost none of the inquired measures received very strong responses.

Third, with the exception of clean-up time, the respondents were rather neutral when asked about displaying hygiene-related information on public touchscreens. This is in line with the results regarding perception and hygiene measures on public displays. Nonetheless, clean-up time was a strongly desired function, which is also easy to communicate on a display. In the next phase of this work, we developed our hygiene concept to investigate these different aspects further.

Finally, there was a very strong correlation between how concerned a respondent was about COVID-19 and how interested they were in seeing hygiene information on public displays. Therefore, there is a segment of users who strongly want to see hygiene information on shared screens.

5 HYGIENE CONCEPT FOR PUBLIC TOUCHSCREENS

To gain deeper insight into what kind of hygiene-related information—if any—should be displayed on public touchscreens, we developed a general-purpose public display concept. The concept was designed in such a way that it could be applied on any public touchscreen.

Figure 3: An overview of the hygiene concept and the existing public display application on top of which it was implemented. The hygiene concept displays a panel on the right side, providing hygiene information and explaining the touch traces. Touching the display produces a trace on the screen. For the current user, the traces are green, and for past users, the traces are red.

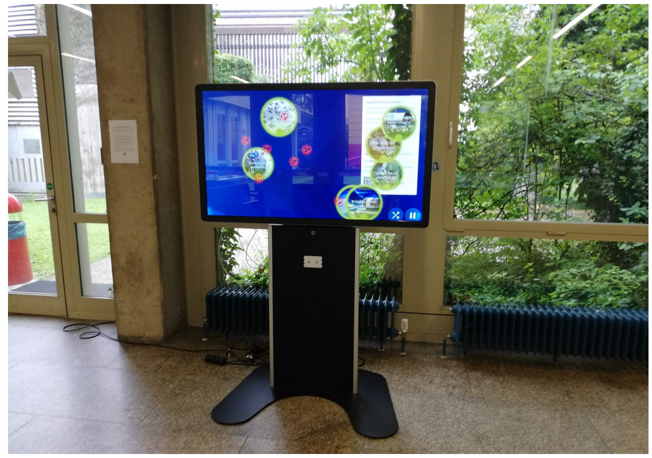

Figure 4: Our hygiene concept application deployed at one of the three deployment locations.

We gathered feedback about our hygiene concept in two ways. First, we deployed the prototype in three locations, in different buildings of two universities. Second, we deployed an online version that allowed users to experience the prototype remotely on their own devices. Both versions were linked to a feedback questionnaire. Participants who filled in the questionnaire could opt in for a raffle of three 30 EUR vouchers.

5.1 Concept and Implementation

Our concept has two key components: touch visualization, and a hygiene panel. We implemented the concept on top of an existing touchscreen application (Figure 3).

Touch visualization First, our concept visualizes the exact points where users have touched on the screen. We implemented three types of touch visualizations: fingerprints, viruses, and circles. We decided on these three visualizations in a brainstorming session, where our intent was to experiment with visualizations that highlight different aspects of the interaction. The fingerprint brings focus to the touch itself, whereas the virus brings focus to the possible risks. At the same time, the circle is a more abstract representation. The application randomly chooses one of the visualizations on startup. The visualization changes automatically every three hours.

The current user's touches are visualized in green, and all past users are shown in red. For our investigation, we implemented a simple mechanism where 30 seconds of inactivity would change all the currently green touches to red and increase the user counter; any new touches would be considered a new user. For a more accurate prediction of when the user changes, motion tracking could be used [32].

Hygiene panel Second, the concept displays a panel that contains three types of hygiene information: when the display was last cleaned, how many people have touched the display since, and how much time has passed since the previous user. Additionally, it explains the meaning of the touch visualization, and displays a link or a QR code for accessing the feedback questionnaire. The QR code was used in the public deployments, and the web link was used in the remote version for faster access to the survey.

We implemented our concept on top of an existing application, CommunityMirror [28, 44], using Angular. CommunityMirror is an application for large touchscreens that displays information in bubbles that hover across the screen. Users can click on the bubbles to open up a more detailed view of their contents, such as news articles. The bubbles can also be dragged to a different location. Our focus with this work, though, was not interaction with CommunityMirror, but rather the touch visualizations and hygiene information. Our concept is functionally independent of CommunityMirror, and it could be added to any public touchscreen application. We also added a logging system that saves all interactions with the prototype, such as the coordinates of touches.

5.2 Public Deployments

We conducted a field study to gather early interaction data and feedback for our hygiene concept. The COVID-19 pandemic made this challenging since the locations where we could deploy our prototype did not have much traffic due to nation-wide regulations. As such, we treat these deployments as a pilot study, which is more strongly supported by our online deployment, as reported later.

We deployed the prototype in three different locations. One was deployed in a large lobby in a university building (Figure 4). Under normal conditions, this location has considerable traffic, consisting mostly of students but also staff and visitors to the university. The second deployment location was in a lobby of another building belonging to a different university. This location was generally more quiet, but would still — under normal conditions — have a steady flow of students and employees. The third deployment was installed in a large kitchen/break room, where university employees held breaks and had meetings.

In all locations, we attached an advertisement next to the display that informed passersby of our research and that we are looking for feedback on the hygiene concepts. We also provided a bottle of disinfectant, which we encouraged people to use before and after touching the display. Touching was not mandatory; people could also just observe the display and provide feedback.

These deployments ran for around four weeks. We went to the locations around once a day at which point the displays were cleaned and the application was reset, restarting the timers and clearing the screen of any touches. For this prototype deployment, we did not include other mechanisms for removing touches.

5.3 Online Deployment

Due to COVID-19, and our subsequent concerns that gathering feedback through a public deployment would be difficult under the current circumstances, we also published an online version of our prototype. This allowed us to reach individuals who currently avoid public locations, and who would not have under the current circumstances participated in our study using a public touchscreen.

The online version enabled participants to experience the prototype using their own device, such as a tablet or laptop. We implemented a check that prevented the prototype from being accessed on smartphones and other small-screen devices. This was because our study was focused on communicating the design and functionalities of the hygiene concept and what it would look like if encountered on a public display. Small screens would not have worked well for this purpose. Also, smartphones are very private devices and as such they are fundamentally different from public displays, for which our prototype was intended.

In the online version, we changed the QR codes to a web link, which participants could click directly to open the questionnaire. In the questionnaire, we made it clear that our concept was intended for *public* touchscreens that other people might use too, and not for private devices. We advertised the deployment via mailing lists.

5.4 Results: Usage Statistics

In our public deployments, we had a total of 952 screen touches from an estimated 60 users. This number of users is relatively low, which was an unfortunate consequence of the COVID-19 pandemic, as not many people frequented the deployment locations due to nation-wide restrictions. Nonetheless, we provide a brief analysis of the logged interactions, which might provide preliminary insight into the impact of the different touch visualizations.

5.4.1 Usage per Condition. Out of 60 users and 952 touches, 20 users (33.3%) interacted during the fingerprint condition, generating 487 touches (51.2%). In the circles condition, 34 users (56.7%) touched the display a total of 368 times (38.7%). Six users (10%) touched the display during the virus condition, for a total of 97 touches (10.2%).

5.4.2 Number of Overlapping Touches. We calculated the times when users touched a spot where a prior user's touch was visible. For fingerprints, 73 of the touches (15.0%) overlapped with previous touches. These came from seven users (35%). For circles, 30 of the touches (8.2%) overlapped with previous touches, belonging to five users (15.6%). In the virus condition, 30 touches (30.9%) overlapped with previous touches, belonging to two users (33.3%).

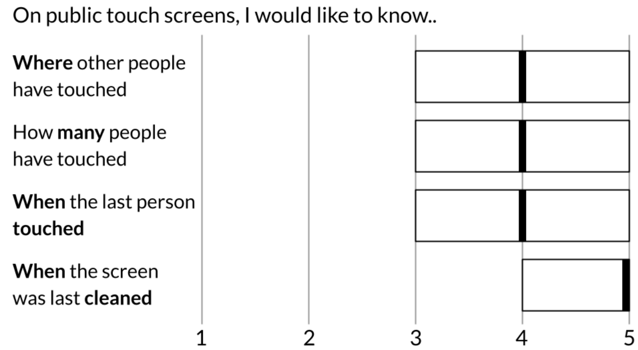

Figure 5: Participants stated on a 5-point scale whether they would like to see four kinds of hygiene information on public screens. The thick, black lines represent the medians, and the boxes represent the inner quartiles.

5.4.3 Average Distance of Touches from Prior Touches. For every touch, we calculated the distance to the nearest touch trace from another person, to see how strongly users would avoid touching the traces. The fingerprints had an average distance of 209 pixels to the nearest touch trace. The circles had an average distance of 359 pixels, while the viruses only had on average of 114 pixels.

5.5 Results: Feedback Questionnaire

We received 77 valid responses to our feedback questionnaire. Six of them came from the public deployments, and 71 from the online deployment. There were seven additional responses to the questionnaire, which we removed as they were submitted in the same time frame and were filled unusually quickly. SoSci, our survey tool, gave a high degradation value for these entries (200–300), suggesting that they were of low quality. In the following subsections, we used the Wilcoxon Signed-Rank test to compare statements.

The respondents' average age was 27 (SD = 8.5), consisting of 39 males, 35 females, and three non-binary persons. 47 were students, three were unemployed, and 27 were professionals in various fields.

5.5.1 Demand for hygiene information. Participants rated how important different hygiene-related information on touchscreens was to them (Figure 5). Generally, hygiene information was seen as important. Participants agreed that they would like to see where on the screen other people have touched (Md = 4), how many people have touched the screen since it was last cleaned (Md = 4), and how much time has passed since the last person touched the screen (Md = 4). Lastly, participants strongly stated that they would like to know how much time has passed since the screen was cleaned/disinfected (Md = 5). Cleanup time was significantly more preferred than any other information ($p < 0.001$).

5.5.2 Visualization feedback. Participants rated the three different visualization symbols by answering three statements: whether the symbols were easy to understand, whether they were appropriate for visualizing touches on a screen, and whether the symbol would prevent them from touching that spot on the screen (Figure 6).

The fingerprints were reportedly very easy to understand (Md = 5). The viruses were also understandable (Md = 4), while the

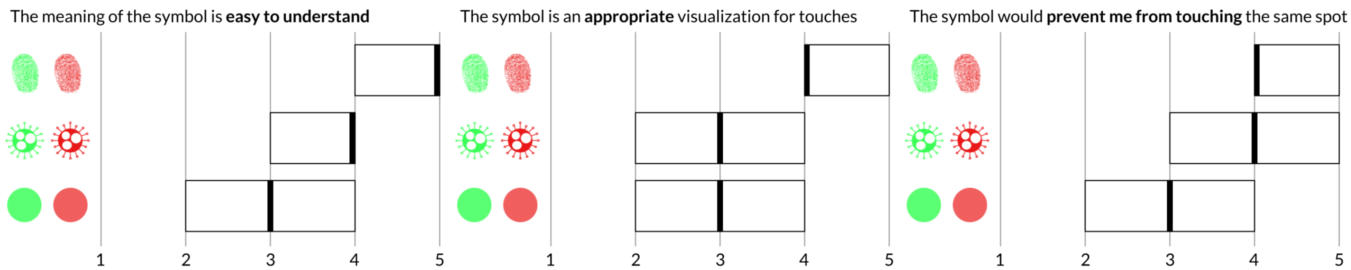

Figure 6: Participants rated the touch visualizations by responding to three statements: whether they are easy to understand, whether they are appropriate for visualizing touches, and to what extent they would affect their choice to touch a point on a screen. The statements were on a 5-point scale, where 1 = strongly disagree, 5 = strongly agree. The thick, black lines represent the medians, and the boxes represent the inner quartiles.

circles were rated neutrally (Md = 3). Differences between all three statements were statistically significant ($p < 0.01$). The fingerprints were also appropriate for visualizing touches (Md = 4), whereas both the viruses and circles were rated neutrally (Md = 3). Differences between fingerprints and the other two were statistically significant ($p < 0.001$), but there were no differences between the viruses and circles. Finally, users estimated that both the fingerprints and the viruses on a screen would prevent them from touching the same spot (Md = 4). Similar to the other statements, circles were rated neutrally (Md = 3). Differences between circles and the other two were statistically significant ($p < 0.001$); there were no differences between fingerprints and viruses.

Participants also provided further insight into their reasoning. The *fingerprints*, unsurprisingly, were rated positively due to their clear affordance to touch. Participants believed that their meaning would be clear without instructions. A few participants believed that the fingerprints might make them not want to touch the display at all:

> *"The fingerprints give a good indication of which areas are safer to touch, but at the same time they can also act as a deterrent and make the user to avoid the touch-screen, even though the risk would potentially be higher on a touchscreen without the prints."*

> *"I would be more disgusted if I saw the fingerprints of others. That can be positive because I then disinfect the screen, but it can also lead to non-use if I don't have anything to clean it with."*

As for the *viruses*, participants believed that they would more clearly highlight the "danger" of touching a shared screen. However, this was largely seen as a negative; that it might foster a fearful environment, and imply the presence of diseases where there are none. Some examples of these comments include:

> *"Just because someone used the screen before me doesn't mean that everyone is sick and spreading viruses."*

> *"Viruses used on a display is fear mongering. It doesn't seem neutral."*

> *"I think that it adds an unnecessary degree of panic when we should be far more worried about things like masks etc."*

> *"They are exaggeratedly deterrent. They suggest that any touch on this spot would transmit viruses and thus possibly make you sick, although this is very unlikely. Their appearance is distracting and intrusive."*

The circles were seen as problematic due to their abstract and non-specific nature. Some participants highlighted that this might unintentionally encourage even more touches, as the circles might be confused for other functions, or seen as an invite to touch them:

> *"Circles seem less daunting, but could be confusing and act as a prompt to press something."*

> *"It's the 'press the big red button' issue, at least for me. I may mistake it for guidance on where to press."*

> *"A bit more abstract and they could tempt younger people to play around with [the display], to leave more prints than normal."*

5.5.3 General Points and Concerns. Participants made interesting points and expressed concerns about touch visualizations not specific to a certain visual design. Some participants believed that such a feature might in fact invite more interaction than before:

> *"I feel like initially, it may actually incentivise people to touch the screen more, because they would want to play around with such a new feature. 'Haha, look, my finger is leaving a trail of dots. Let's touch this some more!', that sort of thing. Though after a while it could be helpful, once one has understood what they mean."*

At the same time, some participants believed that it might make people simply avoid the display altogether:

> *"Personally, I would rather not know where the display was touched because I am more disgusted."*

> *"I would not want to know how many people have touched the screen to be honest. I like to stay ignorant in some way."*

Other highlighted challenges were that the touch traces might focus on the most critical parts of the UI, and threaten privacy:

> *"Although it initially seems useful, I think that the major problem is that the fingerprints will be concentrated on the most used regions (eg a "next" or "pay" button) which you can't avoid. Additionally, there might be security concerns for PIN entry etc."*

5.6 Summary and Discussion

Interestingly, all four of our tested hygiene functions were rated more favorably than in the first online survey. All four functions were rated positively (Md = 4–5). However, again, information about when the display was last cleaned was the most critical piece of information to respondents (Md = 5).

The fingerprints were clearly rated most favorably. They were reportedly very easy to understand and an appropriate way to visualize touches. Respondents also believed the fingerprints to make them avoid touching a location on a screen where a fingerprint is visible. The virus symbol was also seen as somewhat effective based on our rating, but was seen as notably less appropriate than the fingerprint. In fact, viruses invoked the strongest reactions from participants, who stated that displaying viruses on a public display creates unnecessary fear. The circle, on the other hand, was rated neutrally in all statements, being the least effective overall.

Our interaction logs from the public deployments showed that the viruses attracted significantly fewer users than the fingerprints and circles. This seems to be well in line with the feedback, as users felt that displaying viruses on a screen was too much. A logical result, then, is that passersby would avoid the screen completely if virus symbols are present.

Our study also revealed some potential challenges for touch traces. First, there is a risk that certain designs of touch traces could unintentionally promote playful behavior, which is often observed in public display interaction [2, 39, 49, 53]. This was highlighted by a few participants, and also, our log data shows that a surprisingly large number of touches overlapped with prior touches, particularly with the circle visualization (33.3%). We refrain from making strong conclusions from our log data under these unusual conditions, but such effects of touch visualizations should be studied further. Playful interaction is often seen as a positive phenomenon because it tends to attract more users and foster the social aspects of interaction [39, 40]. However, from a hygiene perspective, this type of unintended or even "unnecessary" interaction may be risky.

Second, if not properly designed, touch traces could give away information that users do not want to disclose to others. This is particularly critical for screens with authentication mechanisms, so that the user's PINs, gestures, and passwords are not revealed [25, 27, 54]. Additionally, users typically do not want to reveal what content they were interested in [5, 6, 36] or what opinions they voiced on opinion polls [8, 22, 51, 55].

Third, the touch traces might quickly populate the most critical UI elements, like buttons. In this respect, the CommunityMirror [28] application actually lent itself well to the concept, since it was based on randomly placed information bubbles that moved across the screen; it did not have statically placed UI elements. Later users could therefore not infer from the touch traces what the previous users had been doing.

6 DISCUSSION AND DESIGN IMPLICATIONS

In this section, we draw upon the results from both our online survey and our hygiene concept deployment. We first summarize our findings in regard to our three primary research questions. Afterwards, we formulate design implications for considering hygiene on public touchscreens.

RQ1: *How do people perceive and consider hygiene on public displays, and how has COVID-19 affected them?* Generally, participants reported a moderate degree of awareness for hygiene on public displays. Hygiene considerations and measures when using private devices were very low, which served as a baseline for our investigation. Compared to private devices, participants reported that they more often considered hygiene on public displays and occasionally avoided their use. Other measures like disinfecting and washing hands was also more common with public displays.

Participant reported a slight decrease in the use of some public displays as a result of the pandemic. This suggests a modest shift towards alternative methods, like buying online tickets instead of using a ticket machine. Still, at least part of this decrease is likely a result of the pandemic regulations, as people were likely to go out less and some locations with public displays were at times closed.

RQ2: *What kind of hygiene information do people want to see on public touch displays before use?* The clearly desired piece of information was when the display has been cleaned. Our other investigated measures (number of prior users, time since last user, and visualization of touch spots) received a generally neutral response in our initial inquiry in the online survey. However, the investigation of our hygiene concept, where these measures were demonstrated in practice, yielded more positive results across the board. Therefore, our research overall suggests that there is demand for improved hygiene measures on public touchscreen. This demand was particularly strong among those who also had strong concerns about COVID-19.

RQ3: *How do people feel about seeing the touches of prior users on touchscreens, and what is the most preferred design for such visualizations?* Our investigation into the visualization of prior users' touch points yielded interesting but mixed results. Out of the three investigated visualizations (fingerprints, viruses, and circles), the fingerprints were clearly the most preferred and received the most positive feedback. However, the response to the visualizations was not always positive, as some people thought they go too far and some thought they were distracting.

6.1 Designing for Hygiene on Public Touchscreens

6.1.1 Implement Cleanup Mechanisms. The most critical piece of hygiene information to people is *when the public touchscreen has been cleaned.* It is also a piece of information that requires very little space on the screen, and should, therefore, not be distracting, or seen as "fear mongering". As such, we recommend that designers and practitioners implement mechanisms on their displays to communicate the cleanup time.

On the interface level, cleanup time can be a simple text box in the corner, showing the time of the cleanup and how long ago it was. Naturally, mechanism must be put in place so that the cleanup time can be set. With modern authoring and management tools this can be achieved easily, and can be controlled remotely. Alternatively, the displays could have a hidden function to update the cleanup time (e.g., long press in a remote corner), allowing for the cleaning staff to update it on the spot.

Also, cleanup mechanisms could be easily taken further. For example, displays could alert the cleanup staff after a certain number of touches or users, or after critical parts of the screen have been covered by touches.

6.1.2 Inform Rather Than Warn: Use Subtle Fingerprints for Visualizing Touches.

The fingerprints were clearly favored as a visualization for touches. They are easy to understand, and neutral in their meaning. In contrast, the virus symbol reportedly had too negative connotations, putting too much focus on possible dangers. This suggests that hygiene measures should aim to be neutral – to *inform* rather than *warn*.

However, some participants disliked the visualizations altogether, stating that they would not want to know about prior touches. Indeed, too much focus on hygiene may discourage some users and make them avoid the display completely. This isn't bad *per se*; after all, the point of offering this information is to help users decide whether to interact, and they are completely within their rights to avoid the display. But it is also critical to not overdo it, so that we do not distract users from the display's true purpose, and that we do not foster concerns that may not be there.

As such, it may be worth implementing touch traces in a more subtle manner. For example, the traces could be transparent, thereby blending into the screen. Another solution might be to only visualize areas with a lot of touches. A third possibility might be to not display the current user's touches until they have left the display. After all, it is the other people's traces that users should avoid, not their own.

6.1.3 Consider an Adaptive Interface for Hygiene Improvement.

Some adaptive UI solutions for public displays already exist, for example, to adapt to the user's height [46], number of users [31], or to provide more secure authentication [27]. In smartphone contexts, dynamically adaptive UIs have been developed to, e.g., make users reach far-away UI elements during one-handed interaction [12]. Similar principles could be applied on public touchscreens to steer users away from areas that have been touched by others. This could be as simple as moving buttons from one corner to another, or switching from a vertical button layout to a horizontal layout.

Another useful approach is to design constantly moving UI elements. A good example of this is the CommunityMirror [28, 44] that we deployed our hygiene concept on. The basic interactive elements, the information bubbles, repeatedly move across the screen with a randomized starting position. Such designs lend themselves well to hygiene improvement, as touches are spread more evenly across the entire screen instead of focusing on fixed locations. These solutions would also be easy to adjust so that instead of being completely random, the elements' positioning and trajectories would avoid the most touched areas.

Adaptive and/or randomized UIs have two key strengths. First, for a more subtle hygiene solution, they can work in the background and do not require any visualizations in and of themselves. At the same time, they can be combined with touch traces, if desired. Adaptive interfaces would also improve touch traces, as they would prevent populating fixed locations quickly. Second, adaptive UIs also protect the users' privacy, as their interactions with the screen are difficult to infer without fixed screen elements.

6.2 Limitations and Future Work

A limitation in our work is that we did not investigate the long-term impact of hygiene measures on public displays. Our focus was on investigating the current impressions of users and their needs for hygiene information, and on developing hygiene concepts for this purpose. Therefore, the impact of hygiene information on public display use and user behavior should be studied. The impact may also vary based on the purpose of the display, its location and setting, and the amount of traffic in the area. This impact should be studied in different settings and with longer deployments [32]. In particular, the effect of touch visualizations should be studied further and more comprehensively, to generate more detailed designs that work ideally for the purpose and to understand their impact on the display's use.

Another interesting direction for hygiene improvement might be to detect unusual behavior on public touchscreens and study possible interventions to encourage hygiene practices. Unusual behavior might be, for example, playful behavior where playfulness is not expected (e.g., long dragging motions across the screen when the UI only contains clickable elements, drawing or writing on the screen when the screen doesn't support it), or prolonged interactions where brief interaction periods are expected. Examples of possible interventions would be different types of reminders about hygiene, or even pauses or changes in the system's accepted input.

Finally, adaptive interfaces for hygiene improvement should be studied in different settings to understand their impact on usage and usability, and to developed new types of adaptations. For some applications, e.g., frequently used ticket machines and ATMs, changing the position of UI elements might confuse users and require them to search for particular features that they expect to be in familiar locations. There are many potential solutions to improving the usability of adaptive interfaces, such as making the adaptations very subtle or gradual, or adding animated sections where the elements appear in their familiar positions and move quickly to another location, supporting the user's recognition of those elements.

7 CONCLUSION

In this work, we investigated how public touchscreens could be improved with hygiene measures, so that potential users could stay safe and be informed of the risks. Overall, our work suggests that there is demand for improved hygiene measures, and this demand is especially strong among those who have strong concerns of COVID-19. In particular, people want to know how long it has been since the display was last cleaned. We also experimented with visualizing the touches of past users, so that new users could avoid touching the same locations on the screen. A visualization using a fingerprint symbol was received most positively, but there are still some challenges related to such visualizations. Visualizing touches with a virus symbol was received negatively by many, as it was seen as unnecessary fear mongering. Therefore, it seems that while people want increased awareness of hygiene, it should be done in a rather neutral manner — to leave the choice to them, and not preemptively warn them of danger. Based on our results, we discussed design implications for hygiene on public displays. We believe that our work has potential to make public touchscreen interaction safer and support hygiene awareness.

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