Mask removal isn't always convenient in public! – The Impact of the Covid-19 Pandemic on Device Usage and User Authentication

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ABSTRACT

The ongoing Covid-19 pandemic has impacted our everyday lives and demands everyone to take countermeasures such as wearing masks or disinfecting their hands. However, while previous work suggests that these countermeasures may profoundly impact biometric authentication, an investigation of the actual impact is still missing. Hence, in this work, we present our findings from an online survey (n=334) on experienced changes in device usage and failures of authentication. Our results show significant changes in personal and shared device usage, as well as a significant increase in experienced failures when comparing the present situation to before the Covid-19 pandemic. From our qualitative analysis of participants' responses, we derive potential reasons for these changes in device usage and increases in authentication failures. Our findings suggest that making authentication contactless is only one of the aspects relevant to encounter the novel challenges caused by the pandemic.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile devices**.

KEYWORDS

usable security, mobile devices, authentication, biometrics, Covid-19

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1 INTRODUCTION

In late 2019 a new coronavirus, referred to as Covid-19, appeared and in the following months quickly spread around the globe, resulting in a worldwide pandemic. As a response, many countries imposed measures against the spread of the virus, including lockdowns, hygienic rules (such as wearing masks in public and regular use of disinfectants), social distancing mandates, and contact tracing [3, 4, 29]. However, strictness, effectiveness and form of the imposed measures varied greatly depending on countries, numbers of infections, and progress of the pandemic.

The virus and measures against it had major implications on countries around the world, their economies, public health and daily life of citizens. While there is previous work on the effect of the pandemic on humans, both physiologically and psychologically, changes to their interaction with devices as well as applications and, specifically on authentication, are mostly unexplored – even though several technical solutions were proposed [20, 25]. In particular, authentication is relevant as we expect the pandemic to have a strong impact here, for example, in the form of impairments of face recognition systems due to wearing masks or fingerprint systems failing due to the use of hand sanitizer [6, 33]. Moreover, authentication became more relevant in public spaces because of digital test and vaccination certificates that became mandatory at many places, as well as apps to check-in digitally for contact tracing. Nonetheless, we also expect changes to the interaction with devices in public and private spaces [1, 27]. On one hand, devices can become a potential source of spreading the disease when shared in public. On the other hand, device usage gets more important in personal life, for work, and as a means to connect with others during times of social distancing [10]. A change in usage of personal and shared devices also has implications for authentication systems that are not yet fully understood.

The aim of this paper is to confirm, if the pandemic had indeed an impact on those areas, as well as to understand the root causes and practical relevance. We contribute an online survey with 334 participants from various countries exploring changes to people's use of personal and shared devices, as well as authentication behavior due to the pandemic. We evaluate reported device interaction before and during the pandemic and provide an in-depth qualitative analysis and discussion of the reasons behind these changes. Our findings can serve to obtain a better understanding of external

factors on device interaction and different strategies to cope with changing environments.

2 RELATED WORK

In the following, we discuss previous work on the impact of the Covid-19 pandemic on people and their usage of technology and influences of the pandemic on security, particularly authentication research.

2.1 The Covid-19 Pandemic and Its Impact on People and Technology Use

The Covid-19 pandemic impacts people and their technology usage, not only by the virus itself, but also by the countermeasures put in place by governments to deal with the crisis [19, 23]. A major factor impacting people and their behavior are the multiple types of risk people perceive, including illness, secondary health conditions, economic, socio-behavioral, and institutional risks [23]. It is important to note that people are affected differently by the situation as strictness, and form of the imposed countermeasures varied greatly depending on countries [8, 22]. Moreover, the different age groups do not face the same risk for a severe course of the disease [32]. Especially, older adults are at higher risk and thus, see stronger impacts, for example, on their autonomy, requiring them to adapt their behavior [19].

Studies have found a significant increase of technology use in various contexts [1]. In particular, researchers have found an increase in usage of mobile devices [27]. The reasons for this increase are manifold, ranging from perceived social isolation, to concerns about the pandemic, as well as tracking apps [1]. Additionally, many people had to abruptly shift to remote work in 2020, with more hybrid forms of working in more recent month [31]. The pandemic has also introduced more people to technology that previously had no access to it [10]. While the increase in technology usage is interesting, no previous work has investigated the change in technology use by focusing on personal and shared devices. As these devices often require different forms of authentication, we investigate them in our survey.

2.2 Influences of the Covid-19 Pandemic on Security and Authentication

The main objectives for user authentication have shifted over the years; from security first in the beginning, over privacy and legal issues thereafter, to handling the changes introduced by the Covid-19 pandemic today [30]. Recently, researchers suggested switching to contactless forms of authentication, for example, face recognition [17, 18], contactless fingerprint reader [21], or authentication based on palm vein and palm print image fusion [25]. Thereby, traditional authentication approaches such as PIN or password entry become less relevant and are replaced by biometric systems [17]. Nevertheless, previous works suggests that biometric authentication is influenced by the ongoing pandemic [33]. In particular, face recognition may need additional steps to be used in public contexts with current measures requiring people to wear masks in public [26, 33]. While early research suggests that biometric systems may still work (to some extend) [18], a systematic evaluation of users' experiences with these systems is still missing. Hence, in this work, we conducted a survey to assess these experiences and unveil the various reasons why authentication systems may fail.

3 ONLINE QUESTIONNAIRE

The main goal of this work is to understand, first, the impact of the pandemic on device usage behavior in different contexts, and second, the impact on different authentication types. To this end, we conducted an online survey.

3.1 Survey Design

The survey was divided into three parts: (1) understanding device usage before and during the pandemic, (2) device authentication, focusing on the failures resulting from applying the precaution measures, and (3) demographics.

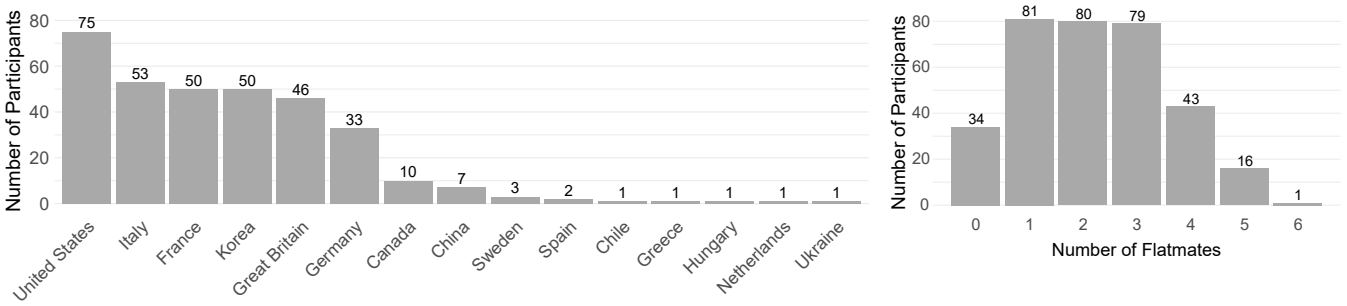
In the survey, we defined three contexts a person could be in: *private*,*semiprivate*, and *public*. The private context denotes the person's place of residence, or simply, home [24]. Semiprivate places are places with limited access, including, for example, work [13]. Finally, we used the term public to define places that commonly used among strangers [24]. Moreover, we categorized the devices as *personal* and *shared*. The personal devices such as smartphones and smartwatches are devices that belong to a single person. On the other hand, we defined shared devices as devices shared among two or more people [15] (including public devices).

We started the survey with a question on participants' device usage frequency before the pandemic. We used an 8-item Likert scale, ranging from very rarely to very often, and not applicable. The next part of the questionnaire focused on the most threatening phase of the pandemic. To stimulate participants' memory to remember, we first asked them to select one or more months, when they started to feel threatened by the pandemic. We specified the months between January 2020 and June 2021. This question was followed by a free text question, to understand the reason behind their selection. The device usage frequency question was asked again, corresponding however this time related to the pandemic phase they felt most threatened at.

In the second part, focusing on authentication methods, we first asked participants for the authentication types they actually use. The options were: knowledge-based, possession-based, and identity-based, as presented by Jain et al. [11, 12]. Next, we asked an open-ended question, to describe the most common authentication failures participants encountered, due to the pandemic. The last question in this part was about the frequency of authentication failure, both before and during the most threatening phase of the pandemic. Lastly, in the demographics part, we asked the participants on their age, gender, level of education, country of residence, and finally, the number of flatmates.

3.2 Participants and Recruitment Process

To compare our findings to previous work, we looked at the selection of countries they used, for example, studies comparing the different countermeasure put into place [5] or the effects on people's live around the globe [8]. The majority of these studies mainly included China, South Korea, Italy, France, the United Kingdom, and the United States of America. Following the paradigm



(a) Number of people from each country. **(b) People sharing the same household.**

Figure 1: Insights into the demographics of the participants taking part in our survey. Left: the number of participants listed by their country of residents. Right: the number of additional people with which participants share a household.

of other works, we used Mechanical Turk[1] and Prolific[2] to recruit participants from the selected countries. Recruiting was done between June and August 2021. We aimed for selecting 50 participants from each country. However, recruiting participants from China and Sweden was not successful. Furthermore, some participants reported different countries of residents in our demographic questions than they had specified on the crowd worker platforms. The total number of participants is 334 (111 female, 218 male, and 5 other), ages varied between 18 and 67 (M=32.57, SD=10.25). For education, participants stated that they had a Bachelor's degree (171), a Postgraduate degree (97), high school or college graduation (65), or less than high school (1). To get a better grasp of the study population and their living context we collected participants' residence and number of people in their households (see Figure 1). To distinguish between personal devices and shared devices in private contexts, we asked our participants on the number of people they share the same household with (see Figure 1b).

3.3 Data Analysis

To analyze the qualitative responses, we applied open coding on our interview data, followed by inductive category development [16]. We did this to identify patterns in participants' opinions and thoughts. Once all the interviews were completed, three researchers open coded the responses, iteratively refining, merging and summarizing through discussion among the research team. This process generated 66 open codes. We then conducted an online affinity diagram of the open codes [7]. Next, we organized the codes into categories, which were then further refined into themes using an online whiteboard[3]. For analysis of our quantitative data, we applied non-parametric tests because we only have ordinal data. Moreover, as we always compare two groups (before the pandemic and during the pandemic), we directly performed Wilcoxon Sign-Rank tests. Effect sizes are calculated from the Z statistic divided by the square root of the sample size (with r <.1 small, <.3 medium, and <.5 large effect).

[1]https://www.mturk.com, last accessed on April 4, 2022
[2]https://prolific.co, last accessed on April 4, 2022
[3]Miro Online Whiteboard. https://miro.com/de/online-whiteboard, accessed on April 4, 2022.

4 RESULTS AND DISCUSSION

We identified three main themes in our qualitative analysis, outlined below. The first two themes were identified in the responses to our question concerning experienced changes in devices' overall usage, while the third theme resulted from our question regarding authentication failures. Within each theme, we report on the number of uncodeable responses (e.g., answers unrelated to the question, answers we could not interpret, or answers not in English). We use participant IDs for direct quotes and the pronoun "they" for all participants to ensure anonymity. Moreover, we enrich our qualitative responses with quantitative data matching the theme and follow up each theme with the corresponding discussion.

4.1 Personal Devices: Less in Public, More at Home

In our survey, many participants mentioned that their personal device usage changed due to the pandemic (n=149). While others did not mention that their personal device usage changed (n=110) and some gave answers that were uncodeable (n=75). The responses indicating a change in personal device usage could be further categorized into *more* (n=132), *less* (n=26), and *shifted* (n=21) device usage (note that some participants mentioned multiple changes). While more and less indicate the frequency of usage, shifted usage denotes the changes of the device usage from one context to the other (e.g., from using personal devices at work to at home due to working from home).

Out of the total 132 statements on more device usage, we observed that the majority of the responses indicate more usage at home (n=79) or in general (n=46), i.e., no context is explicitly mentioned. In the remaining statements, six indicated more personal device usage at work and only one indicated more personal device usage in public (n=1). On the other hand, statements declaring lesser device usage were all tied to the public context (n=26) and responses about a shift in device usage indicated a shift from work (n=18) or university/school (n=3) to their home.

While 20.45% of the participants did not provide reasons for an increased personal devices' usage, others included more specific reasons for their changing behavior, which we grouped into four categories. First, we identified an increase in personal device usage

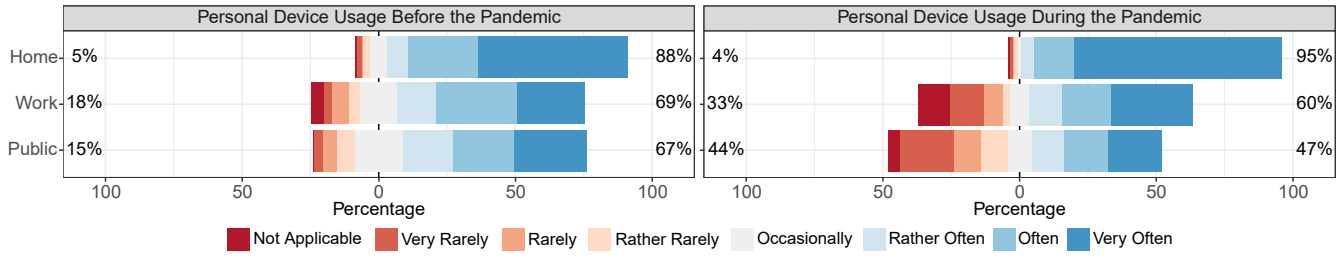


Figure 2: Subjective ratings of personal device usage. Left: before the Covid-19 pandemic. Right: during the Covid-19 pandemic.

at home because of social distancing or lockdown (n=63). Second, participants reported checking the news more often – mostly at home (n=24). For instance, one participant said *"I wanted to stay in touch with news and health updates via the media (P345)."* Third, we found that some mentioned an increase in usage of their personal devices at home due to working from home, homeschooling activities, and employment status (n=23). Note that this is additional and not shifted device usage from work/school: *"As I was working from home, I was using my personal laptop side by side to my work laptop (P189)."* Last, participants stated that they either used their devices to calm down, or to interact with their families and friends (n=15). The reasons for less personal device usage in public were because participants stated that they would either try to not touch their personal devices to reduce the infection risk (n=18), avoid public in general and stay home (n=6), or they did not provide a reason (n=2). For a shift in device usage, the reason was always homeschooling or remote work (n=21).

Subjective Likert-items. We used Likert-items to assess the frequency of participants' personal device usage, before the pandemic and during the most threatening phase(s). Both of these questions were asked once for each of the following contexts (home, work, and public). We presented an 8-item Likert scale (*not applicable, very rarely, rarely, rather rarely, occasionally, rather often, often, very often*). Here, *not applicable* means that participants did not use a personal device in that context at all. When matched with the free text statements, this option reflected when device usage was impossible or unfeasible. For instance, during the most threatening phases of the pandemic, more participants marked being in public or at work as Not Applicable, as explained by P6 noting *I was working from home, and so most of the "at work" categories are irrelevant (P6).* P69 adds *I didn't work during this phase and didn't go out very much (P69).* The results are plotted in Figure 2. To analyze the data, we compared the responses for before and during the pandemic within each context, finding significant differences in all contexts (see Table 1). In summary, we found a significant increase of personal device usage at home ($p<.001$) and a significant decrease of usage at work ($p=.002$) or in public ($p<.001$).

Discussion. From our results, one can observe a trend towards more personal device usage in general. This can be attributed to a range of factors, including news and media consumption and the necessity of working or learning from home; confirming results from related work [10, 31]. However, it also points towards a need for rethinking authentication for personal devices: Given that they are used for different tasks now, such as working from home. Moreover, we observed a decreased usage of personal devices in public. While one reason often mentioned was being less in public in general, another factor seems to be the risk of infection by contamination of the personal devices. We see potential for a conflict here, as personal devices are regularly used to check-in (for contact tracking or notification) or show proof of vaccination. Thus, future work should investigate alternative options, for example, by using smartwatches with contactless interaction.

4.2 A Setback for Shared Devices

The second theme formed around usage of shared devices. Many participants stated that their usage of shared devices changed due to the pandemic (n=113). Nevertheless, others did not mention any changes in shared device usage (n=146) and same gave uncodeable answers (n=75). The responses mentioning a change in shared device usage can be further categorized into *less* (n=133) and *more* (n=13) device usage.

Following the same pattern as for personal devices, we also considered the three contexts (home, work, public) to cluster the open-text responses. We observed that the decrease of shared device usage mostly related to public contexts (n=51) or in general (n=42), i.e., no context is explicitly mentioned. Less usage at work was highlighted in 29.3% of the statements, and only statement reported less shared device at home. Contrary, only some participants stated an increase in shared device usage (n=13), nine defined the context as location, and four mentioned the public context.

While some participants did not provide reasons for their changed shared device usage (n=23), most explained their answers (n=123). The reasons of the decrease of shared device usage were primarily tied to the pandemic and the following tightening measures. For instance, participants highlighted that they wanted to reduce the risk of an infection with the virus (n=94) or could not use shared devices due to lockdown (n=16). For instance, P21 elaborates: *"I made sure not to use shared devices[,] mostly in public and work situation due to risk of infection (P21)."* Anecdotally, participants also reported workarounds for situations where shared devices could not be avoided: *"[..] using cleaning wipes on devices at work, whereas before I never did this (P380)."* Additionally, some participants mentioned that they mostly used shared devices at work and either cannot access these devices anymore due to remote work or they became personal devices (n=13). *"Shared tablets at work became assigned personal tablets instead (P333)."* On the other hand, some participants stated an increase in shared device usage (n=13). Here, two participants did not provide a reason, but the other either said

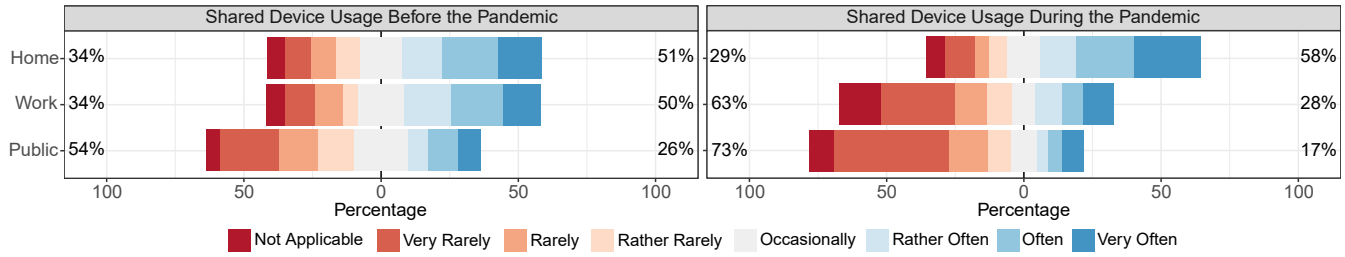


Figure 3: Subjective ratings of shared device usage. Left: before the Covid-19 pandemic. Right: during the Covid-19 pandemic.

that they shared more devices at home to share them with flatmates (n=8), for example, to spend time together playing games, watching movies, or for homeschooling their kids, or they used more shared devices in public for self-checkout (n=3).

Subjective Likert-items. To better understand the effect of the pandemic on shared device usage, we used Likert-items to assess participants' shared device usage, asking for before the pandemic and during the most threatening phase(s). Both of these questions were again asked once for each of the following contexts (home, work, and public) with 8-point Likert items (see Figure 3). Moreover, we compared the responses for before and during the pandemic within each context, finding significant differences in all contexts (see Table 1). In summary, we found a significant increase of shared device usage at home ($p<.001$) and a significant decrease of usage at work ($p<.001$) or in public ($p<.001$).

Discussion. Our results show a clear picture: participants decreased their interactions with shared devices in almost all contexts, with only small exceptions such as sharing with flatmates due to spending more time at home. However, there are also interactions that are hard to avoid like using ATMs, making card payments or requesting a green light as a pedestrian. We believe this illustrates opportunities for digitization in many areas, e.g. by using personal devices as interfaces for those shared objects. At the same time, it is not clear if users would want such a shift.

4.3 Increasing Numbers of Authentication Failures

In addition to overall device usage, we were also interested to gain insights on privacy implications resulting due to the pandemic. To that end, we asked participants if they had experienced any authentication failures during the pandemic. Participants highlighted that they have experienced failures (n=141), while others said that they have not experienced any authentication failures related to the pandemic (n=143). Moreover, some gave answers that were uncodeable (n=50). From the participants mentioning failures, some experienced biometric-based authentication failures (n=127), knowledge-based authentication failures (n=42), and failures of two-factor authentication (n=3); please note that some reported multiple failures.

For the biometric-based authentication failures, participants said that face recognition (n=93) or fingerprint reader (n=34) did not work properly. For *face recognition* failures, participants mostly mentioned face masks as a problem (n=79), while two mentioned changes in their weight, or not shaving their face (n=1), both due to the pandemic. *"I get more weight in these months, and my face changed a little, which impact my face ID authentication. (154)."* Moreover, some mentioned face recognition failing, but provided no reasons (n=6) or reasons unrelated to the pandemic about face recognition in general (n=5). For *fingerprint reader* failures, participants highlighted gloves (n=7), hand sanitizer (n=6), and handwashing (n=4) as failure reasons: *"At times, after sanitizing my hand the fingerprint [sensor] didn't seem to recognize my finger (P90)."* Participant 6 hypothesizes *"[..] the constant hand-washing seemed to make the problem even worse. In the end, I switched to facial recognition, which was more reliable but also required mask removal (not always convenient in public!) (P6)."* Again, some did not give reasons for failures (n=10) or mentioned general problems (n=7).

However, participants even linked some *knowledge-based authentication* failures directly to the pandemic, participants voiced that they forgot their pin/password due to the increased stress caused by pandemic (n=4) or a change in usage frequency due to the pandemic (n=3). Along the same lines, also a few participants reported to have mistyped their pin/password due to wearing gloves (n=3). Additionally, many did not provide a reason for forgetting their pin/password (n=22) or gave reasons not linked to the pandemic (n=10).

Subjective Likert-items. To investigate, if there is an increase in experienced authentication failures, we asked participants to rate the frequency of experienced failures before and during the pandemic on a 7-point Likert scale (1=very rarely to 7=very often). Participant stated that they rarely experienced failure before the pandemic (Md=2, IQR=3), while they stated that during the pandemic they experience failures occasionally (Md=4, IQR=3.5). Here, we found a medium effect comparing before and during the pandemic ($W=1240$, $Z=-9.14$, $p<0.001$, $r=0.35$). We can conclude that participants subjectively experienced more authentication failures during the pandemic than before.

Discussion. While contactless authentication systems are helpful to reduce the risk of infection by avoiding to touch potentially contaminated surfaces, this is not the only change imposed by the global pandemic. For example, if the fingerprint remains only faintly visible after excessive handwashing or use of disinfectants, a contactless fingerprint reader is likely to not work in some situations [21]. As a consequence, we believe that our community needs to rethink biometric authentication systems. First, we should critically assess which types of biometric authentication remain unaffected by novel challenges such as the ongoing pandemic (e.g., iris scanner [28]) or research novel paradigms that do not suffer

Table 1: Pairwise comparison of Likert-items on device usage for before and during the Covid-19 pandemic. For personal and shared devices within the three different contexts (home, work, and public). We applied the Wilcoxon Signed-rank test.

		Mdn_{Before}	IQR_{Before}	Mdn_{During}	IQR_{During}	Z	p	r
Personal Devices	Home	7	1	7	0	-6.32	<.001	0.24
	Work	6	2	5	5	3.08	.002	0.11
	Public	5	3	4	4	8.34	<.001	0.32
Shared Devices	Home	5	3	5	3	-3.85	<.001	0.14
	Work	4	4	2	4	8.90	<.001	0.34
	Public	3	4	1	3	7.98	<.001	0.30

from the same issues (e.g., functional biometrics [14]). Second, we should take the opportunity to consider important factors neglected in the past (e.g., user impairments [2]). When done correctly, we have the chance to improve user authentication for everyone.

5 IMPLICATIONS

With the worldwide shift to more private contexts, current authentication methods for personal devices may need to be rethought. Fundamentally, raising the question *whether a person at home really needs to authenticate or not*, when this user is staying at home for longer periods of time. In public contexts, more attention should be drawn towards *the concerns of using personal phones in public*, especially when these devices are needed to check-in or verify vaccination status. Although shared device usage is reported to have significantly decreased in public, *interactions with shared devices cannot be completely averted*. We believe that there is a need for *novel interface methods to enable personal devices to interact with public ones*, without privacy or safety compromises. Moreover, it remains unclear if the commonly used biometric authentication methods are efficient. With the increased need to disinfect all touched surfaces, comes *the need for non-tactile interfaces for authentication*, for instance mid-air gestures [9], or physiological features that are not affected by infection prevention measures [33].

Limitations. We acknowledge that participants' countries of residence are unbalanced. However, we did not analyze the responses based on geographical location, and thus, it does not strongly affect the validity of our findings. Moreover, our participants represent a higher educated population. Hence, our findings may not generalize to the total population.

Future Work. We want to extend this work by conducting follow-up interviews with the participants, to get deeper insights. Additionally, we would increase our sample and investigate the changed behaviors based on the country of residence, to investigate the impact of various backgrounds and pandemic strategies upon different types of interactions.

6 CONCLUSION

In this work, we presented our findings from a survey (n=334) about the impact of the Covid-19 pandemic on device usage and user authentication in different contexts. The analysis of participants responses showed that users are more prone to using their personal devices in private contexts rather than in public, where users are less likely to use shared devices in work and in public. This changing behavior results of mainly abiding to official lockdown rules, shifting work conditions, and the fear of being infected. Multiple users faced authentication failures due to pandemic-related measures, such as fingerprint and face recognition. We believe that this work contributes as a guideline for the possible impact of the pandemic upon future interfaces and interaction solutions.

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REFERENCES

[1] Ala Sarah Alaqra and Agnieszka Kitkowska. 2021. *Impact of Intrinsic Factors and COVID-19 Pandemic on the Use of Technology.* Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3411763.3451669

[2] Sarah Andrew, Stacey Watson, Tae Oh, and Garreth W. Tigwell. 2020. A Review of Literature on Accessibility and Authentication Techniques. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (Virtual Event, Greece) *(ASSETS '20).* Association for Computing Machinery, New York, NY, USA, Article 55, 4 pages. https://doi.org/10.1145/3373625.3418005

[3] Steven Arzt, Andreas Poller, and Gisela Vallejo. 2021. *Tracing Contacts With Mobile Phones to Curb the Pandemic:Topics and Stances in People's Online Comments About the Official German Contact-Tracing App.* Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3411763.3451631

[4] Gustavo Betarte, Juan Diego Campo, Andrea Delgado, Pablo Ezzatti, Laura González, Álvaro Martín, Rodrigo Martínez, and Bárbara Muracciole. 2021. Proximity tracing applications for COVID-19: data privacy and security. In *2021 XLVII Latin American Computing Conference (CLEI).* 1–10. https://doi.org/10.1109/CLEI53233.2021.9640202

[5] Elizabeth Gibney. 2020. Whose coronavirus strategy worked best? Scientists hunt most effective policies. *Nature* 581, 7806 (2020), 15–17.

[6] Marta Gomez-Barrero, Pawel Drozdowski, Christian Rathgeb, Jose Patino, Massimmiliano Todisco, Andras Nautsch, Naser Damer, Jannis Priesnitz, Nicholas Evans, and Christoph Busch. 2021. Biometrics in the Era of COVID-19: Challenges and Opportunities. *arXiv preprint arXiv:2102.09258* (2021).

[7] Gunnar Harboe and Elaine M. Huang. 2015. Real-World Affinity Diagramming Practices: Bridging the Paper-Digital Gap. In *Proc. 33rd Annual ACM Conf. Human Factors in Computing Systems.* ACM, New York, NY, USA, 95–104. https://doi.org/10.1145/2702123.2702561

[8] Solomon Hsiang, Daniel Allen, Sébastien Annan-Phan, Kendon Bell, Ian Bolliger, Trinetta Chong, Hannah Druckenmiller, Luna Yue Huang, Andrew Hultgren, Emma Krasovich, et al. 2020. The effect of large-scale anti-contagion policies on the COVID-19 pandemic. *Nature* 584, 7820 (2020), 262–267.

[9] Shaoyan Huang, Sakthi PB Ranganathan, and Isaac Parsons. 2020. To touch or not to touch? Comparing Touch, mid-air gesture, mid-air haptics for public display in post COVID-19 society. In *SIGGRAPH Asia 2020 Posters.* 1–2.

[10] Rahat Jahangir Rony, Syeda Shabnam Khan, Anik Sinha, Anik Saha, and Nova Ahmed. 2021. *"COVID Has Made Everyone Digital and Digitally Independent": Understanding Working Women's DFS and Technology Adoption during COVID Pandemic in Bangladesh.* Association for Computing Machinery, New York, NY, USA, 202–209. https://doi.org/10.1145/3429360.3468212

[11] Anil Jain, Ruud Bolle, and Sharath Pankanti. 1996. *Introduction to Biometrics.* Springer US, Boston, MA, 1–41. https://doi.org/10.1007/0-306-47044-6_1

[12] Anil Jain, Lin Hong, and Sharath Pankanti. 2000. Biometric identification. *Commun. ACM* 43, 2 (2000), 90–98.

[13] Adam Kjær Søgaard, Bo Jacobsen, Michael Utne Kærholm Svendsen, Rune Lundegaard Uggerhøj, and Markus Löchtefeld. 2021. *Evaluation Framework for Public Interactive Installations.* Association for Computing Machinery, New York, NY, USA, 79–86. https://doi.org/10.1145/3469410.3469418

[14] Jonathan Liebers and Stefan Schneegass. 2020. Introducing Functional Biometrics: Using Body-Reflections as a Novel Class of Biometric Authentication Systems. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–7. https://doi.org/10.1145/3334480.3383059

[15] Tara Matthews, Kerwell Liao, Anna Turner, Marianne Berkovich, Robert Reeder, and Sunny Consolvo. 2016. " She'll just grab any device that's closer" A Study of Everyday Device & Account Sharing in Households. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 5921–5932.

[16] Philipp Mayring. 2014. Qualitative Content Analysis: Theoretical Foundation, Basic Procedures and Software Solution. (2014). http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173

[17] Muhammad Irwan Padli Nasution, Nurbaiti Nurbaiti, Nurlaila Nurlaila, Tri Inda Fadhila Rahma, and Kamilah Kamilah. 2020. Face Recognition Login Authentication for Digital Payment Solution at COVID-19 Pandemic. In *2020 3rd International Conference on Computer and Informatics Engineering (IC2IE)*. 48–51. https://doi.org/10.1109/IC2IE50715.2020.9274654

[18] Pauline Norstrom and Anekanta Consulting. 2021. Has Covid increased public faith in facial recognition? *Biometric Technology Today* 2021, 11 (2021), 5–8. https://doi.org/10.1016/S0969-4765(21)00121-1

[19] Novia Nurain, Clara Caldeira, and Kay Connelly. 2021. *Older Adults' Experiences of Autonomy During COVID-19 Pandemic.* Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3411763.3451674

[20] Uzoma I. Oduah, Ifeanyichukwu F. Kevin, Daniel O. Oluwole, and Josephat U. Izunobi. 2021. Towards a high-precision contactless fingerprint scanner for biometric authentication. *Array* 11 (2021), 100083. https://doi.org/10.1016/j.array.2021.100083

[21] Uzoma I. Oduah, Ifeanyichukwu F. Kevin, Daniel O. Oluwole, and Josephat U. Izunobi. 2021. Towards a high-precision contactless fingerprint scanner for biometric authentication. *Array* 11 (2021), 100083. https://doi.org/10.1016/j.array.2021.100083

[22] Aydin Ozkan, Gulcin Ozkan, Abdullah Yalaman, and Yilmaz Yildiz. 2021. Climate risk, culture and the Covid-19 mortality: A cross-country analysis. *World Development* 141 (2021), 105412. https://doi.org/10.1016/j.worlddev.2021.105412

[23] Kathleen H Pine, Myeong Lee, Samantha A. Whitman, Yunan Chen, and Kathryn Henne. 2021. *Making Sense of Risk Information amidst Uncertainty: Individuals' Perceived Risks Associated with the COVID-19 Pandemic.* Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3411764.3445051

[24] Julie Rico and Stephen Brewster. 2010. Usable Gestures for Mobile Interfaces: Evaluating Social Acceptability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for Computing Machinery, New York, NY, USA, 887–896. https://doi.org/10.1145/1753326.1753458

[25] Kala H S, Shreya Kumar, Rakshanda B Reddy, Nishanth Shastry, and Rounak Thakur. 2021. Contactless Authentication Device using Palm Vein and Palm Print Fusion Biometric Technology for Post Covid World. In *2021 International Conference on Design Innovations for 3Cs Compute Communicate Control (ICDI3C)*. 281–285. https://doi.org/10.1109/ICDI3C53598.2021.00063

[26] Krish Sethi, Simrit Kaul, Ishan Patel, and Sujatha R. 2021. FaceLock Homes: A Contactless Smart Home Security System to Prevent COVID Transmission. In *2021 Sixth International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)*. 75–79. https://doi.org/10.1109/WiSPNET51692.2021.9419453

[27] Kata Rebeka Szücs and Dóra Maros. 2020. Mobile Usage during COVID-19. In *2020 IEEE 3rd International Conference and Workshop in Óbuda on Electrical and Power Engineering (CANDO-EPE)*. 000035–000040. https://doi.org/10.1109/CANDO-EPE51100.2020.9337789

[28] Shejin Thavalengal, Petronel Bigioi, and Peter Corcoran. 2015. Iris authentication in handheld devices - considerations for constraint-free acquisition. *IEEE Transactions on Consumer Electronics* 61, 2 (2015), 245–253. https://doi.org/10.1109/TCE.2015.7150600

[29] Christine Utz, Steffen Becker, Theodor Schnitzler, Florian M. Farke, Franziska Herbert, Leonie Schaewitz, Martin Degeling, and Markus Dürmuth. 2021. *Apps Against the Spread: Privacy Implications and User Acceptance of COVID-19-Related Smartphone Apps on Three Continents.* Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3411764.3445517

[30] Chalee Vorakulpipat and Ekkachan Rattanalerdnusorn. 2021. Evolutionary Consideration on User Authentication: Security, Privacy, and Safety. *IT Professional* 23, 5 (2021), 38–43. https://doi.org/10.1109/MITP.2020.3034617

[31] Yun Wang, Ying Liu, Weiwei Cui, John Tang, Haidong Zhang, Doug Walston, and Dongmei Zhang. 2021. *Returning to the Office During the COVID-19 Pandemic Recovery: Early Indicators from China.* Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3411763.3451685

[32] Zunyou Wu and Jennifer M McGoogan. 2020. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. *jama* 323, 13 (2020), 1239–1242.

[33] Yicheng Zhou. 2021. Evaluation of biometric recognition in the COVID-19 period. In *2021 2nd International Conference on Computing and Data Science (CDS)*. 243–248. https://doi.org/10.1109/CDS52072.2021.00049