"Sometimes I feel that I'm being left behind": Exploring Computing Device Use by People with Upper Extremity Impairment During the COVID-19 Pandemic

Brittany Lewis
bflewis@uri.edu
The University of Rhode Island
Kingston, Rhode Island, USA

Paige Courtemanche
pcourtemanche@uri.edu
The University of Rhode Island
Kingston, Rhode Island, USA

Krishna Venkatasubramanian
krish@uri.edu
The University of Rhode Island
Kingston, Rhode Island, USA

ABSTRACT

In this paper, we explore how *computing device use* by people with upper extremity impairment (UEI) was affected by COVID-19. Someone with UEI has reduced use of their shoulders, upper arms, forearms, hands, and/or fingers. We conducted six (6) semi-structured interviews with participants with UEI in the US. We found that people with UEI increased computing device use during COVID-19 not only for remote interactions but also in person. Additionally, social distancing for COVID-19 safety created the need for new assistive technology (AT), authentication requirements, and communication platforms, which introduced their own accessibility barriers. We also found that personal protective equipment (PPE) created new barriers during computing device use, which often caused people with UEI to choose COVID-19 safety over the usability of their computing devices. Based on these findings, we describe future opportunities to make computing devices more accessible for people with UEI to manage the shifts in computing device use introduced by COVID-19.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility technologies**.

KEYWORDS

upper extremity impairment, personal computing devices, COVID-19

ACM Reference Format:
Brittany Lewis, Paige Courtemanche, and Krishna Venkatasubramanian. 2022. "Sometimes I feel that I'm being left behind": Exploring Computing Device Use by People with Upper Extremity Impairment During the COVID-19 Pandemic. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '22 Extended Abstracts), April 29-May 5, 2022, New Orleans, LA, USA.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3491101.3519647

CHI '22 Extended Abstracts, April 29-May 5, 2022, New Orleans, LA, USA

ACM ISBN 978-1-4503-9156-6/22/04…$15.00
https://doi.org/10.1145/3491101.3519647

1 INTRODUCTION

Despite the existence of COVID-19 vaccines [76], COVID-19 remains an ongoing and large-scale threat in the US due to vaccine hesitancy [68] and the emergence of new variants (e.g., the omicron variant) [78]. The threat from COVID-19 has created the need for new COVID-19 safety precautions that have rapidly altered the way we access critical aspects of our lives including work [59], school [15, 18], health care [14, 71], and social interaction [20, 24, 37, 79]. However, often when technology evolves to meet new problems, accessibility is not considered and is instead left as an afterthought. Therefore, the rapid changes during COVID-19 introduced new accessibility barriers for people with disabilities [25]. One change caused by COVID-19 has been an increase in computing device use [70]. However, pandemic-influenced reliance on computing device use has created accessibility barriers for people with upper extremity impairment (UEI)[1] who already faced barriers during computing device use prior to COVID-19 [34].

In the US, the official response to COVID-19 has been fragmented [41]. Additionally, some businesses or educational institutions implemented their own policies for COVID-19 safety. Therefore, in this work we focus on *two* main **COVID-19 safety precautions**, which were introduced by COVID-19 and experienced broadly in the US: social distancing and the use of personal protective equipment (PPE) [75]. These precautions helped preserve the safety of everyone, including vaccinated individuals [8, 30]. We aim to explore how COVID-19 and its safety precautions have affected *computing device use*[2] for people with UEI. Our **goal** is to answer three core research questions: (1) how has COVID-19 broadly affected computing device use for people with UEI?; (2) how have people with UEI adapted their computing device use to remain socially distanced from others?; and (3) how has PPE impacted computing device use for people with UEI?

To answer these questions we conducted six (6) semi-structured interviews with participants with UEI in the US. These interviews provided insight into the experiences that people with UEI have when using computing devices during COVID-19 and allowed us to make several observations. First, we found that people with UEI used computing devices more often to interact both remotely and face-to-face with others (e.g., showing electronic documents to

[1] A person with UEI is anyone with reduced or no range of motion, strength, endurance, speed, and/or accuracy associated with movement in the shoulders, upper arms, forearms, hands, and/or fingers. Over 20 million people in the US have conditions that lead to UEI [72].
[2] In this work, we focus on general purpose computing device use. We define computing device use as both the interaction with the device's physical hardware as well as any applications or internet-based interactions that occur using the device.

avoid fomite-mediated transmissions). Second, we discovered that social distancing for COVID-19 created the need for new assistive technology (AT), authentication requirements, and communication platforms, which introduced their own accessibility barriers. Third, use of PPE created new accessibility barriers for people with UEI that caused participants to prioritize COVID-19 safety over usability of their computing devices[3]. We analyze these findings and call for further research to make computing devices more accessible to the shifts introduced by COVID-19 for people with UEI.

2 RELATED WORK

Prior research has been done on various interactions between people with UEI, COVID-19, and computing. These works fall into three main categories: accessibility for people with disabilities during COVID-19, the impact of COVID-19 on people with UEI, and computing device accessibility for people with UEI.

Recent works have looked at various aspects of accessibility during the COVID-19 pandemic, although this remains an under-explored area of research [42]. Existing research has focused on the impact of online learning for children with disabilities [25, 54, 56, 64]; improving the accessibility of online healthcare information [25, 29]; supporting caregivers for people with dementia [26]; addressing communication barriers for hospital patients including patients with UEI [6]; and increasing website accessibility during COVID-19 [20, 73]. None of these works focus specifically on people with UEI, nor do they address computing device use broadly in order to explore new accessibility barriers that may have arisen during COVID-19. One work [25] used tweets to analyze accessibility concerns related to COVID-19 including barriers to grocery store delivery, distance learning, health information access, and communication. This work provides a broad overview of accessibility issues introduced by COVID-19. In our work, however, we wanted to understand more specifically how people with UEI have interacted with computing devices during the COVID-19 pandemic.

Research on the impact of COVID-19 on people with UEI has been limited. Two works have addressed the broad impact of COVID-19 on the health and well-being of adolescents with cerebral palsy, a condition which sometimes leads to UEI [10, 40]. Additionally, while not specific to people with UEI, COVID-19 has introduced the need for everyone to wear increased PPE. Works from both during and prior to COVID-19 have focused on creating more usable experiences while wearing PPE [13, 21, 27, 38, 44, 45]. Thus far, prior work has not address the impact of COVID-19 or PPE on computing device use for people with UEI as we address in this work.

Work prior to COVID-19 highlighted the need for accessible computing for people with UEI. Prior work has focused on the development of new AT such as foot-based AT [31, 61], gestures [74], head-based AT [16, 48, 49, 58, 65], robotic extremities [12, 32], eye-based AT [3, 9, 60, 67, 81], brain computer interfaces [5, 39, 63], voice-based AT [62, 66], tongue-based AT [55, 80], facial interactions [22, 50, 67], dwell-based entry [2], customized touch entry [52], and custom AT [4, 33]. Less work has focused on broadly understanding computing device use for people with UEI. These works include studying the usability of touchscreens [7, 23, 51], smartwatches [47], smart phones [53], authentication [28, 43], and sensing systems [34]. These studies provide important background; however, COVID-19 has created new computing device usability challenges for people with UEI, which are the focus of this work.

[3]In the rest of the paper we use the term *usability* to mean computing device usability, unless otherwise specified.

3 METHOD

To understand how the computing device use of people with UEI during COVID-19, we conducted remote, semi-structured interviews with six adults with UEI. Our procedure was approved by our institution's ethics board. All participants had to be over the age of 18, have UEI, and use at least one computing device regularly. The authors used a broad definition of UEI. Everyone who identified with having UEI was invited to participate. Participants were recruited through e-mail lists of local non-profits or due to their involvement in previous studies. Participant demographics are in Table 1.

For safety reasons, the first author conducted interviews online over Zoom [83]. All participants were given the option of Zoom or any other video calling platform of their choice. During the interview, audio was recorded. For privacy reasons, we did not record video to avoid collecting more data than necessary. Consent was obtained for recording, and the first author confirmed when the recording began before asking any questions. The first author also took field notes of participant responses. During two interviews, the second author attended and took notes. Participants were compensated with a $10 gift card. Our interviews were centered around three core questions: (1) how has COVID-19 broadly affected computing device use for people with UEI?; (2) how have people with UEI adapted their computing device use to remain socially distanced from others?; and (3) how has PPE impacted computing device use for people with UEI?

After the interviews, the audio recordings were transcribed. Field notes were inserted at the start of the transcripts. Any personal details about the participants were removed from the transcripts to preserve privacy. The transcription documents were then analyzed to produce our findings. All analysis was conducted remotely using word processing software. During analysis, the first two authors went through the interview transcripts separately to group data into descriptive categories by participant. The first and second author then grouped findings into themes with appropriate text evidence. The first author lead a discussion with all three authors about the themes and organization. This was done iteratively through a series of meetings and organizational documents until the themes from Section 4 emerged.

4 FINDINGS

In order to understand how COVID-19 impacted computing device use, we first asked about the computing devices, assistive technology (AT), and personal protective equipment (PPE) used by our participants. These results are in Table 1. All of our participants used PPE when using computing devices in addition to the AT they had used prior to the pandemic. Importantly, PPE was usually used outside of participants' homes. Therefore, PPE was used only with devices that participants took with them when leaving their homes (e.g., smart phones, tablets, laptops). Next we discuss how

ID	Age	Gender	Disability	Computing devices	Context of use	AT used	PPE Used
P1	20	Man	**Muscular dystrophy:** 90 degree contractures in arms, contractures in hands that limit mobility and dexterity	Desktop, laptop , smart phone	In-person university course work and personal use	None	Mask, gloves*, face shield*
P2	59	Man	**Spinal cord injury:** Gross motor function when sitting, no motor function when lying down	Laptop, iPhone, iPad	Personal use	Mouth Stick, Voice Assistant	Mask
P3	59	Man	**Multiple sclerosis:** Unimpaired use of left hand, right (dominant) hand can grab objects but lacks strength and endurance	Laptop, iPhone	Personal use	Speech recognition AT, Voice Assistant	None
P4	66	Woman	**Amputation:** Both arms are amputated below the elbow. No impairment above the elbow	Work laptop, personal laptop, iPhone	Work from home, personal use	Speech recognition AT, dowel, mouth stylus	Mask
P5	51	Woman	**Cerebral palsy:** Fine motor tasks are difficult and slow, some fine motor tasks are impossible	Work PC laptop, personal Mac laptop, iPhone	Work from home, personal use	None	Mask
P6	74	Woman	**Spinal cord injury:** Fine motor tasks are challenging and have become increasingly so over time	Desktop, combination laptop/tablet, iPad, smart phone	Work from home and remote university course work	Speech recognition AT; adaptive keyboard/mouse	Mask

*P1 stopped using the gloves and face shield in May of 2020 due to the usability concerns outweighing the safety benefits

Table 1: Demographics of participants including age, gender, and disability as well as the computing devices, assistive technology (AT), and personal protective equipment (PPE) used by participants. The manufacturer of the computing device is included when identified by the participant. Typically, participants reported that they only used PPE outside of their homes; therefore they only use PPE with devices that they take with them when leaving home such as phones, tablets, and sometimes laptops.

COVID-19 and its safety precautions impacted computing device use for people with UEI.

4.1 People with UEI increased their computing device use during COVID-19 both remotely and in-person

During the COVID-19 pandemic, use of computing devices was essential for our participants to access goods and services and to connect with others. ***All our participants increased their computing device use including for remote work or school, connecting to others remotely, and when meeting face-to-face with others.***

Remote interactions using computing devices increased for people with UEI during COVID-19. For example, P5 used computing devices to connect to others and access important services, *"I'd be totally isolated with COVID without the technology. I do a lot of...ordering for food stuff online...so it's just a great big plus. And it does help me stay connected. You know, I don't really like to call people. I don't like to use the phone so much and I usually get tired. So it's good to have the capacity to text people and to email people to stay in touch that way. So...I'm always grateful for the technology that we do have available today, and that I personally have available to me. If I didn't have a smart phone or a laptop I'd be in a very bad place."* Computing device use during COVID-19 increased not only for personal use, but also for attending work or school remotely [57]. Three of our six participants (P4, P5, and P6) transitioned to working from home. While all these participants had used computing devices for their work before, the transition to remote work meant that activities that had been conducted in person (e.g., meetings) now were done virtually. In addition to remote work, P6 mentioned changes to her university coursework, including more online lectures. Interestingly, she noted how this change had increased accessibility because she no longer had to request lecture recordings. She stated, *"I had asked for the accommodation of being able to video record lectures because I couldn't take notes....Well...what was an accommodation then is actually standard practice now. Because of COVID-19, all the lectures are —even if they're done in person—...they record them."* However, the constant use of computing devices for work and personal use could become problematic. P6 spoke about increased screen fatigue, *"I am aware that I need to get away from it more often. I definitely scheduled breaks, just to get away from the screen for a bit."*

Computing devices were used not only to interact more virtually, but also to interact in-person with others. For example, P1 attended a university within a COVID-19 *bubble*[4]. P1 commented that within his bubble he used his computing devices more for face-to-face interaction. He stated, *"Not interact like send text messages, but actually, physically interact with people. Like showing them stuff on the phone instead of carrying around papers and handing out papers."* He mentioned that this increased COVID-19 safety in a few ways. Firstly, it helped P1 avoid handing materials like papers back and forth. This helped prevent fomite-mediated transmissions[5]. Secondly, he mentioned that the new safety processes within his bubble required him to show electronic confirmations to others in person. He gave an example of this in which he had to use an electronic system to reserve his meals at his university. When he arrived at the dining hall, he displayed a reservation confirmation in order to get food. He stated, *"There's a reservation system for all the dining halls, and...you have to verify that you've*

[4]A bubble is a group or community that avoids seeing anyone outside of that group in person in order to limit the spread of COVID-19 from outside sources [69].
[5]Transmission of the virus through surfaces

reserved electronically. So my phone is always out when I do that." This was implemented in order to limit the number of people in the dining hall at one time and ensure social distancing.

4.2 Social distancing increased the need for new AT, authentication requirements, and communication platforms, which introduced new accessibility barriers

Social distancing required people to limit their face-to-face interactions with others. ***Often our participants had to adopt new AT, authentication requirements, and communication platforms for remote interactions. This new technology often did not fully meet the needs of our participants, resulting in decreased usability.***

As a result of social distancing, computing devices were used for much longer, resulting in the need for new AT. For example, P6 used her computing devices more often in order to work and attend classes remotely. As a result, some of P6's computing device accessories (e.g., mice and keyboards) had become uncomfortable over time. One way that P6 compensated for this was to use Dragon Naturally Speaking[6] [19], *"almost exclusively now"* for work and schoolwork. Dragon was easier to use overall; however, it presented some challenges with the rest of her COVID-19 workflow. One such barrier occurred during the authors' interview with P6. At the start of the interview, P6 encountered challenges connecting her camera to the Zoom meeting. P6 used a different microphone for meetings than she does for Dragon. As she explained, *"The [microphone] I use [for] Dragon...it's just a microphone. So it doesn't pick up as much machine noise and as much ambient noise as the camera one does. Camera one doesn't seem to pick up the speech that well for dictating. Plus, I don't want my camera on all the time."* The use of two different microphones was effective but necessitated switching between them. This decreased usability and occasionally led to issues like the one that occurred during the interview. P6 reported that this happened more often during COVID-19 because she had more online meetings: *"The issue of which microphone I'm using, and switching to cameras and stuff is a much more frequent activity."*

Virtual interaction requires the use of more authentication, which creates accessibility barriers. In addition to increased computing device use, our participants had new software and security requirements for working remotely. This new workplace software required authentication. However, authentication often creates barriers for people with UEI when it makes assumptions about a user's ability to complete motor tasks such as entering a password or positioning a biometric sensor [28, 34, 43]. P5 reported on the increased volume of software and security requirements, *"For the work [computer] I have more PINs now, and passwords because of COVID....to log into the computer we have to sign in. And then we have VPN so we can access our server. And that requires a login. And that's all manual, including getting a text and then putting that password into the computer from a text in order to get to the VPN. And then we have... Jabber, which needs a password...so the need for passwords has increased by a lot."* For P5, authentication is inaccessible because of the fine motor tasks involved. Furthermore, much of the new software she used did not offer options for authentication beyond passwords, which greatly limited her ability to implement an effective workaround. For instance, for P5, fingerprint biometrics were easier to use for authentication than passwords. However, the new software did not offer accessible alternatives like biometrics. She commented, *"None of it's [fingerprint], none of it's touch. All of it's typing."* P5 continued using the new software despite its usability issues as it was essential for working remotely.

Social distancing moved many personal interactions online, resulting in isolation when communication platforms were inaccessible. As the need for virtual interactions increased, more communication platforms were necessary to stay connected to friends and family. In the worst-case scenario, the number of online accounts required for both personal and work-related communication became overwhelming. In order to mitigate this, P5 abandoned several accounts including Facebook, Twitter, and Google. P5 instead used applications, like text or e-mail, that were more accessible to her. She felt unable to use the platforms that others used to stay connected during COVID-19, *"I don't really have access to that part. I have access to other, you know, other ways to keep connected...using more of the older technology, like texting and email, but I don't use the newer stuff…I find them overwhelming actually."* This made it difficult for P5 to connect with others virtually, which is essential during a pandemic when everyone is physically separated from one another. She reported how isolated she felt, *"Sometimes I feel that I'm being left behind, you know, and a little more isolated."*

4.3 PPE used for COVID-19 interfered with some assistive technology that people with UEI used.

PPE such as masks were used to prevent transmission of COVID-19. However, many ATs used by people with UEI to make computing accessible did not work well with PPE. ***This created a conflict between the need for PPE to maintain safety and device usability, which often caused people with UEI to prioritize safety at the expense of usability.***

Masks interfered with with mouth-based AT. Both P2 and P4 used some form of mouth-based AT, which was impeded by masks. P2, who used a mouth stick for his iPad, commented: *"With the iPad, I use a mouse stick. So I couldn't use the mask."* Since he generally used the iPad inside, where he did not often wear a mask, this was usually not an issue. However, P2 often brought his iPad with him when he left the house. He commented, *"When I'm out and about...my iPad's in my backpack."* This raised safety concerns if he were to use the iPad while outside. P4, on the other hand, used a stylus on her iPhone by holding it with her mouth. Sometimes, she pulled down her mask if she was alone and it was safe for her to do so. However, when in public, she often still needed to use her phone, but the mask interfered with its use. She worked around this barrier by sticking the stylus through her mask to type. She explained this process in detail, *"I have an iPhone 6... so I can attach [the stylus] with a shoestring... So I pick [the stylus] up with my mouth and I either answer the phone or start a text or whatever...When I have my mask on, I either pull the mask down and put the [stylus] in my mouth or I leave the mask on and kind of push the stylus through the*

[6]Dragon Naturally Speaking is speech recognition software.

mask – without making a hole – just enough for my lips to hold it and then I use it that way." When she was around others, she put the stylus into her mouth through the mask without removing or making a hole in the mask. Because she was not removing the mask, this method protected her from aerosol transmission of COVID-19. This worked with the type of cloth masks that she used and allows her to continue to stay safe in public places. However, it may not have worked with rigid masks such as many N95 or KN95 masks. Additionally, while this was effective, it was not as comfortable or usable as pulling down her mask to use her stylus.

Masks often muffled voice commands, which impeded the use of voice assistants. Voice assistants can be used on various computing devices by people with UEI to complete tasks without having to type. However, masks often muffled voice commands leading to the voice assistants ignoring or misunderstanding input. Both P2 and P3 used a voice assistant on their iPhones (Siri) to complete various tasks while outside of their homes. P3 succinctly explained how the mask interfered with Siri: *"If I'm on my iPhone, and I try to use Siri with a mask on, it doesn't always recognize my voice. So I type instead."* For P3, while he found voice commands provided increased usability, he was able to type on his phone as a backup. P2, however, was not able to manipulate his iPhone independently without voice commands. Instead, he used a variety of workarounds, which prioritized usability and safety differently depending on the situation. When he had someone with him who could help him, they assisted him in getting the voice commands to work. He commented, *"If I'm with someone, I'll have them maneuver the phone so it will work. If not, I'll just come back in the house and log into my computer or iPad. Without the mask, or if I'm with someone, I can pull my mask down and get what I need to from the phone and then they can put my mask back up."* Getting help from others to pull down his mask preserved usability; however, it caused additional exposure from the person helping him, resulting in less COVID-19 safety. Additionally, P2 did not always have someone around to help him. When he wanted to fix the problem without assistance, he sometimes traveled back home to use his laptop, which he was able to manipulate himself without removing his mask. Sometimes, he was able to avoid going back home by finding quiet areas to prevent ambient noise from interfering with voice commands. With less noise Siri was often able to hear him. This strategy allowed him to avoid being overly inconvenienced. He commented, *"I know enough quiet places in the neighborhood where I haven't had to come back often."*

Masks, gloves, and face shields interfered with authentication, especially facial recognition. P1, who used cloth masks, a face shield, and gloves to protect against COVID-19, reported, *"Facial recognition doesn't really work with a mask on....In the beginning of the pandemic...I wore a face shield and gloves as well. And that didn't really work with a phone. So it was just very inconvenient."* He used various workarounds to log in that balanced different aspects of usability and safety. One workaround P1 used was to log in ahead of time. That way, he would not need to sign in while wearing his PPE. He explained, *"I would sign into my phone before I got out of the car or something, and then put on the gloves, and then just keep it signed in. So, let's say that I needed like an email to like show to somebody then I'd just pull up that email beforehand, then put all the protective equipment, just keep the phone on there and then show it."* Generally, because social interactions have been less spontaneous during COVID-19, he was able to anticipate what he would need and plan appropriately. While this strategy was effective, it presented a security risk by keeping his computing device signed in continuously. As security is one of the main reasons people with UEI use authentication [43], this was not ideal. Later in the pandemic, P1 stopped using the face shield and gloves because the inconvenience of using them outweighed the safety benefits. He continued to use the cloth masks, which interfered with facial recognition. He used passwords and PINs as redundant log-in methods as a workaround. He stated, *"Using PINs and passwords more and being a lot more aware of my timing of logging into things... those are the two biggest things that have definitely changed with COVID."*

5 DISCUSSION

Our results provide us with information about the changes that COVID-19 has had on computing device use for people with UEI. We found that COVID-19 safety was a priority for our participants. Further, COVID-19 has exposed gaps in accessibility research that must be explored to prepare for the future. This is critical not only for the ongoing threat of COVID-19 and its variants, but also due to the frequency of similar respiratory pandemics worldwide [77].

Existing AT and PPE must be adapted to work well together. PPE (e.g., face masks) are not going away any time soon, especially as the spread of COVID-19 variants causes an increase in mask mandates [8]. However, we found that the technologies used by people with UEI (e.g., mouth-based AT, voice recognition) do not work well with PPE. Furthermore, adjusting or removing PPE requires motor tasks which can present additional barriers for people with UEI. For example, when P2 is unable to use voice commands due to his mask, he often relies on others to help him adjust his mask as he is not able manipulate his mask or his phone without help. It is important that people with UEI are able to use AT that they need to access their devices while remaining safe and healthy. It is therefore essential that the AT used by people with UEI is made more tolerant to changes brought on by PPE. Some work has focused on improving facial recognition for people wearing face masks [35, 44]. In fact, Apple has suggested a workaround for their Face ID system for people wearing masks [35]. However, this system requires the user to own and wear an Apple Watch [35]. This may not be practical for people with UEI both due to the high expense of Apple products as well as the fine motor control required to enter a PIN into small devices like the Apple Watch [49]. Additionally, some work has been done on increasing communication while using PPE such as face masks [6, 17]. However, existing work has focused on human to human communication through means such as gestures, clear face masks, and AAC. Further work is needed to adapt voice assistance and voice recognition software to work effectively with PPE friendly communication methods. Furthermore, future designs of protective equipment should consider how they can be altered to be more accessible, such as making it easier to hold a mouth-based pointer device with a mask on, as it is not always possible to replace the technology people already use.

Authentication should be made accessible for people with UEI. Authentication has known accessibility issues for people with

UEI [28, 34, 43]. COVID-19 increased the number of authentication instances necessary to complete tasks. This is especially true for new work-from-home policies. This has created issues for our participants, like P5, who struggled with authenticating to many different programs at her workplace. Authentication must be made accessible for every device and for every application. In addition, organizations such as work places should carefully consider accessibility needs before adopting new technology or security constraints. One approach to address this could involve multiple options for authentication such as the fingerprint authentication favored by P5.

Computing devices should work accessibly and ergonomically over long periods of use. In addition to new technology, during COVID-19, people with UEI have been using computing technology more often and for longer lengths of time. This can lead to accessibility barriers in computing device use over time. Some of these barriers can be addressed by creating easier systems for switching over microphones or creating more ergonomic and adjustable desktop settings for mice and keyboards. It may also be necessary to design additional technology or social solutions that encourage taking breaks during computing device use to avoid fatigue. Prior research has focused on understanding user needs and desires for breaks [36], creating new workplace or computing device changes to decrease fatigue [1, 82], and prompting breaks during workplace activities [11, 46]. However, COVID-19 has raised new concerns about the need for breaks not only during work but also for virtual interactions in our personal lives. Furthermore, more research is needed to determine the specific needs of people with UEI in combating fatigue. For example, AT used by people with UEI may introduce new sources of fatigue during computing device use such as additional eye strain from use of eye gaze tracking, or voice strain from the use of speech recognition software and voice assistants. Additionally, physical break activities such as stretching must be designed to work with the abilities and desires of people with UEI.

5.1 Limitations

Our study has a few limitations. First, this work was completed as part of an interview study intended to understand device authentication during COVID-19. As part of the study, broader questions were asked to understand computing device use during COVID-19. The responses revealed emerging themes that form the basis of our work. However, questions about authentication were asked first in the interview, which may have biased our participants. Second, we only had six participants. While this is not abnormal for work on accessibility, more participants could have provided additional perspectives. For instance, none of our participants needed to work in person during COVID-19. In-person workers may encounter different accessibility barriers. Additionally, interviews were conducted remotely to preserve social distancing of the participants and researchers. However, this may have discouraged participants who face accessibility barriers during remote studies. Finally, all of our participants are from the US. Since the reaction to COVID-19 in the US was different from that of many other countries, our results may not hold for people from other countries or cultures.

6 CONCLUSION

In this paper, we wanted to understand the impact of COVID-19 on computing device use by people with UEI. Therefore, we interviewed six participants with UEI to learn how their computing device use changed during COVID-19. We found that people with UEI used computing devices more frequently during COVID-19 not only remotely but also during face-to-face interactions with others. We also found that new AT, authentication requirements, and communications software used by people with UEI to address challenges due to COVID-19 social distancing created its own accessibility barriers. Furthermore, use of PPE introduced new accessibility barriers to computing device use, which often forced participants to prioritize COVID-19 safety over usability. We then identified future research to make computing devices more accessible for people with UEI: (1) adapting PPE and AT to work well together, (2) increasing the accessibility of authentication, (3) and addressing the challenges of computing device accessibility during long periods of use. Additionally, in the future we hope to conduct a larger scale survey to explore the impact of COVID-19 safety measures on computing device use for people with UEI who have different work situations or safety concerns than those included in this study.

ACKNOWLEDGMENTS

We would like to thank all of the reviewers and participants who provided their time and talents to make this work stronger. This work is supported in part by the National Science Foundation grant CNS-1947022.

REFERENCES

[1] Bengt Ahlström, Sören Lenman, and Thomas Marmolin. 1992. Overcoming Touchscreen User Fatigue by Workplace Design. In *Posters and Short Talks of the 1992 SIGCHI Conference on Human Factors in Computing Systems* (Monterey, California) *(CHI '92)*. Association for Computing Machinery, New York, NY, USA, 101–102. https://doi.org/10.1145/1125021.1125103

[2] Hyunjin Ahn, Jaeseok Yoon, Gulji Chung, Kibum Kim, Jiyeon Ma, Hyunbin Choi, Donguk Jung, and Joongseek Lee. 2015. DOWELL: Dwell-Time Based Smartphone Control Solution for People with Upper Limb Disabilities. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI EA '15)*. Association for Computing Machinery, New York, NY, USA, 887–892. https://doi.org/10.1145/2702613.2732862

[3] Areej Al-Wabil, Arwa Al-Issa, Itisam Hazzaa, May Al-Humaimeedi, Lujain Al-Tamimi, and Bushra Al-Kadhi. 2012. Optimizing Gaze Typing for People with Severe Motor Disabilities: The IWriter Arabic Interface. In *Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility* (Boulder, Colorado, USA) *(ASSETS '12)*. Association for Computing Machinery, New York, NY, USA, 261–262. https://doi.org/10.1145/2384916.2384983

[4] Veronica Alfaro Arias, Amy Hurst, and Anita Perr. 2020. Designing a Remote Framework to Create Custom Assistive Technologies. 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 62, 4 pages. https://doi.org/10.1145/3373625.3418022

[5] F. Aloise, F. Schettini, P. Aricò, L. Bianchi, A. Riccio, M. Mecella, F. Babiloni, D. Mattia, and F. Cincotti. 2010. Advanced Brain Computer Interface for Communication and Control. In *Proceedings of the International Conference on Advanced Visual Interfaces* (Roma, Italy) *(AVI '10)*. Association for Computing Machinery, New York, NY, USA, 399–400. https://doi.org/10.1145/1842993.1843076

[6] Tami Altschuler, Rachel Santiago, and Jessica Gormley. 2021. Ensuring communication access for all during the COVID-19 pandemic and beyond: supporting patients, providers, and caregivers in hospitals. *Augmentative and Alternative Communication* 37, 3 (2021), 155–167. https://doi.org/10.1080/07434618.2021.1956584 arXiv:https://doi.org/10.1080/07434618.2021.1956584 PMID: 34338583.

[7] Lisa Anthony, YooJin Kim, and Leah Findlater. 2013. *Analyzing User-Generated Youtube Videos to Understand Touchscreen Use by People with Motor Impairments*. Association for Computing Machinery, New York, NY, USA, 1223–1232. https://doi.org/10.1145/2470654.2466158

[8] Allison Aubrey, Selena Simmons-Duffin, Rob Stein, and Carmel Wroth. 2021. *Delta Is Surging. Here's What You Need To Know To Stay Safe.* NPR. https://www.npr.org/sections/health-shots/2021/07/17/1017075240/delta-variant-is-spreading-fast-and-new-cases-are-rising-is-time-to-mask-up-agai

[9] Tanya Bafna. 2018. Gaze Typing Using Multi-Key Selection Technique. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility* (Galway, Ireland) *(ASSETS '18)*. Association for Computing Machinery, New York, NY, USA, 477–479. https://doi.org/10.1145/3234695.3240992

[10] Atul R Bhaskar, Mayuri V Gad, and Chasanal M Rathod. 2022. Impact of COVID Pandemic on the Children with Cerebral Palsy. *Indian Journal of Orthopaedics* (2022), 1–6.

[11] Scott A. Cambo, Daniel Avrahami, and Matthew L. Lee. 2017. BreakSense: Combining Physiological and Location Sensing to Promote Mobility during Work-Breaks. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 3595–3607. https://doi.org/10.1145/3025453.3026021

[12] Christian P. Carvajal, Fernando A. Chicaiza, Renato Carvajal, and Víctor H. Andaluz. 2017. Robotic Stimulation for Fine Motor Skills of the Upper Extremities. In *Proceedings of the 2017 9th International Conference on Education Technology and Computers* (Barcelona, Spain) *(ICETC 2017)*. Association for Computing Machinery, New York, NY, USA, 268–271. https://doi.org/10.1145/3175536.3176652

[13] Jack Shen-Kuen Chang, Michael J. Henry, Russ Burtner, Oriana Love, and Courtney Corley. 2015. The Heroes' Problems: Exploring the Potentials of Google Glass for Biohazard Handling Professionals. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI EA '15)*. Association for Computing Machinery, New York, NY, USA, 1531–1536. https://doi.org/10.1145/2702613.2732698

[14] Jin Chen, Cheng Chen, Joseph B. Walther, and S. Shyam Sundar. 2021. Do You Feel Special When an AI Doctor Remembers You? Individuation Effects of AI vs. Human Doctors on User Experience. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, Article 299, 7 pages. https://doi.org/10.1145/3411763.3451735

[15] Zhilong Chen, Hancheng Cao, Yuting Deng, Xuan Gao, Jinghua Piao, Fengli Xu, Yu Zhang, and Yong Li. 2021. Learning from Home: A Mixed-Methods Analysis of Live Streaming Based Remote Education Experience in Chinese Colleges during the COVID-19 Pandemic. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (accepted)* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3411764.3445428

[16] Muratcan Cicek, Ankit Dave, Wenxin Feng, Michael Xuelin Huang, Julia Katherine Haines, and Jeffry Nichols. 2020. Designing and Evaluating Head-Based Pointing on Smartphones for People with Motor Impairments. 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 14, 12 pages. https://doi.org/10.1145/3373625.3416994

[17] American Speech-Language-Hearing Association [n.d.]. *Communicating effectively while wearing masks.* American Speech-Language-Hearing Association. https://www.asha.org/public/communicating-effectively-while-wearing-masks-and-physical-distancing/

[18] Bronwyn J. Cumbo, Tom Bartindale, and Dan Richardson. 2021. Exploring the Opportunities for Online Learning Platforms to Support the Emergency Home School Context. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 347, 11 pages. https://doi.org/10.1145/3411764.3445044

[19] Nuance Communications 2020. *Dragon Speech Recognition.* Nuance Communications. https://www.nuance.com/dragon.html

[20] Jared Duval, Ferran Altarriba Bertran, Siyeng Chen, Melissa Chu, Divya Subramonian, Austin Wang, Geoffrey Xiang, Sri Kurniawan, and Katherine Isbister. 2021. Chasing Play on TikTok from Populations with Disabilities to Inspire Playful and Inclusive Technology Design. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (accepted)* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3411764.3445303

[21] Ran-i Eom and Yejin Lee. 2020. Clothing Design with Wearable Device for Worker's Safe Activity. In *Proceedings of the 14th EAI International Conference on Pervasive Computing Technologies for Healthcare* (Atlanta, GA, USA) *(PervasiveHealth '20)*. Association for Computing Machinery, New York, NY, USA, 400–401. https://doi.org/10.1145/3421937.3421965

[22] Mingming Fan, Zhen Li, and Franklin Mingzhe Li. 2020. Eyelid Gestures on Mobile Devices for People with Motor Impairments. 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 15, 8 pages. https://doi.org/10.1145/3373625.3416987

[23] Leah Findlater, Karyn Moffatt, Jon E. Froehlich, Meethu Malu, and Joan Zhang. 2017. *Comparing Touchscreen and Mouse Input Performance by People With and Without Upper Body Motor Impairments.* Association for Computing Machinery, New York, NY, USA, 6056–6061. https://doi.org/10.1145/3025453.3025603

[24] Verena Fuchsberger, Janne Mascha Beuthel, Philippe Bentegeac, and Manfred Tscheligi. 2021. Grandparents and Grandchildren Meeting Online: The Role of Material Things in Remote Settings. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 478, 14 pages. https://doi.org/10.1145/3411764.3445191

[25] Cole Gleason, Stephanie Valencia, Lynn Kirabo, Jason Wu, Anhong Guo, Elizabeth Jeanne Carter, Jeffrey Bigham, Cynthia Bennett, and Amy Pavel. 2020. Disability and the COVID-19 Pandemic: Using Twitter to Understand Accessibility during Rapid Societal Transition. 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 5, 14 pages. https://doi.org/10.1145/3373625.3417023

[26] Connie Guan, Anya Bouzida, Ramzy Michael Oncy-avila, Sanika Moharana, and Laurel D. Riek. 2021. Taking an (Embodied) Cue From Community Health: Designing Dementia Caregiver Support Technology to Advance Health Equity. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (accepted)* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3411764.3445559

[27] T Hampton, R Crunkhorn, N Lowe, J Bhat, E Hogg, W Afifi, S De, I Street, R Sharma, M Krishnan, et al. 2020. The negative impact of wearing personal protective equipment on communication during coronavirus disease 2019. *The Journal of Laryngology & Otology* 134, 7 (2020), 577–581.

[28] K. Helkala. 2012. Disabilities and Authentication Methods: Usability and Security. In *2012 Seventh International Conference on Availability, Reliability and Security*. IEEE, New York, NY, USA, 327–334. https://doi.org/10.1109/ARES.2012.19

[29] Leona Holloway, Matthew Butler, Samuel Reinders, and Kim Marriott. 2020. Non-Visual Access to Graphical Information on COVID-19. 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 75, 3 pages. https://doi.org/10.1145/3373625.3418015

[30] Andrea Hsu and Alina Selyukh. 2021. *Back To The Office? Not Yet. Companies Scramble To Adjust To The Delta Variant.* NPR. https://www.npr.org/2021/07/30/1022660154/back-to-the-office-not-yet-companies-scramble-to-adjust-to-delta-variant

[31] Xiaozhu Hu, Jiting Wang, Weiwei Gao, Chun Yu, and Yuanchun Shi. 2021. FootUI: Assisting People with Upper Body Motor Impairments to Use Smartphones with Foot Gestures on the Bed. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, Article 436, 7 pages. https://doi.org/10.1145/3411763.3451782

[32] Yuhan Hu, Sang-won Leigh, and Pattie Maes. 2017. Hand Development Kit: Soft Robotic Fingers as Prosthetic Augmentation of the Hand. In *Adjunct Publication of the 30th Annual ACM Symposium on User Interface Software and Technology* (Québec City, QC, Canada) *(UIST '17)*. Association for Computing Machinery, New York, NY, USA, 27–29. https://doi.org/10.1145/3131785.3131805

[33] Amy Hurst and Jasmine Tobias. 2011. Empowering Individuals with Do-It-Yourself Assistive Technology. In *The Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility* (Dundee, Scotland, UK) *(ASSETS '11)*. Association for Computing Machinery, New York, NY, USA, 11–18. https://doi.org/10.1145/2049536.2049541

[34] Shaun K. Kane, Anhong Guo, and Meredith Ringel Morris. 2020. Sense and Accessibility: Understanding People with Physical Disabilities' Experiences with Sensing Systems. 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 42, 14 pages. https://doi.org/10.1145/3373625.3416990

[35] Samantha Murphy Kelly. 2021. *Apple tests new way to unlock an iPhone without removing a face mask.* CNN Business. https://www.cnn.com/2021/02/02/tech/apple-face-id-mask/index.html

[36] Mina Khan, Kathryn Wantlin, Zeel Patel, Elena Glassman, and Pattie Maess. 2021. Changing Computer-Usage Behaviors: What Users Want, Use, and Experience. In *Asian CHI Symposium 2021* (Yokohama, Japan) *(Asian CHI Symposium 2021)*. Association for Computing Machinery, New York, NY, USA, 53–60. https://doi.org/10.1145/3429360.3468180

[37] Erica Kleinman, Sara Chojnacki, and Magy Seif El-Nasr. 2021. The Gang's All Here: How People Used Games to cope with COVID19 Quarantine. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (accepted)* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3411764.3445072

[38] Mareike Kritzler, Martin Bäckman, Anders Tenfält, and Florian Michahelles. 2015. Wearable Technology as a Solution for Workplace Safety. In *Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia* (Linz, Austria) *(MUM '15)*. Association for Computing Machinery, New York, NY, USA, 213–217. https://doi.org/10.1145/2836041.2836062

[39] Kirk L. Kroeker. 2011. Improving Brain-Computer Interfaces. *Commun. ACM* 54, 10 (Oct. 2011), 11–14. https://doi.org/10.1145/2001269.2001275

[40] Byron Lai, Huacong Wen, Tanvee Sinha, Drew Davis, Erin Swanson-Kimani, Cynthia Wozow, Raven Young, Danielle Powell, and James H Rimmer. 2021. The impact of COVID-19 on the lifestyles of adolescents with cerebral palsy in the Southeast United States. *Disability and health journal* (2021), 101263. https://doi.org/10.1016/j.dhjo.2021.101263

[41] Arush Lal, Ngozi A Erondu, David L Heymann, Githinji Gitahi, and Robert Yates. 2021. Fragmented health systems in COVID-19: rectifying the misalignment between global health security and universal health coverage. *The Lancet* 397, 10268 (2021), 61–67.

[42] Jonathan Lazar. 2020. Accessibility Research in the Pandemic: Making a Difference in the Quality of Life for People with Disabilities. 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 1, 1 pages. https://doi.org/10.1145/3373625.3430947

[43] Brittany Lewis and Krishna Venkatasubramanian. 2021. "I...Got My Nose-Print. But It Wasn't Accurate": How People with Upper Extremity Impairment Authenticate on Their Personal Computing Devices. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, Article 379, 14 pages. https://doi.org/10.1145/3411764.3445070

[44] Mohamed Loey, Gunasekaran Manogaran, Mohamed Hamed N. Taha, and Nour Eldeen M. Khalifa. 2021. A hybrid deep transfer learning model with machine learning methods for face mask detection in the era of the COVID-19 pandemic. *Measurement* 167 (2021), 108288. https://doi.org/10.1016/j.measurement.2020.108288

[45] Martina Loibner, Sandra Hagauer, Gerold Schwantzer, Andrea Berghold, and Kurt Zatloukal. 2019. Limiting factors for wearing personal protective equipment (PPE) in a health care environment evaluated in a randomised study. *PloS one* 14, 1 (2019), e0210775.

[46] Yuhan Luo, Bongshin Lee, Donghee Yvette Wohn, Amanda L. Rebar, David E. Conroy, and Eun Kyoung Choe. 2018. *Time for Break: Understanding Information Workers' Sedentary Behavior Through a Break Prompting System*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi-org.uri.idm.oclc.org/10.1145/3173574.3173701

[47] Meethu Malu, Pramod Chundury, and Leah Findlater. 2018. *Exploring Accessible Smartwatch Interactions for People with Upper Body Motor Impairments*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3174062

[48] Meethu Malu and Leah Findlater. 2014. "OK Glass?" A Preliminary Exploration of Google Glass for Persons with Upper Body Motor Impairments. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (Rochester, New York, USA) *(ASSETS '14)*. Association for Computing Machinery, New York, NY, USA, 267–268. https://doi.org/10.1145/2661334.2661400

[49] Meethu Malu and Leah Findlater. 2015. Personalized, Wearable Control of a Head-Mounted Display for Users with Upper Body Motor Impairments. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 221–230. https://doi.org/10.1145/2702123.2702188

[50] Andreia Matos, Vítor Filipe, and Pedro Couto. 2016. Human-Computer Interaction Based on Facial Expression Recognition: A Case Study in Degenerative Neuromuscular Disease. In *Proceedings of the 7th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-Exclusion* (Vila Real, Portugal) *(DSAI 2016)*. Association for Computing Machinery, New York, NY, USA, 8–12. https://doi.org/10.1145/3019943.3019945

[51] Kyle Montague, Hugo Nicolau, and Vicki L. Hanson. 2014. Motor-Impaired Touchscreen Interactions in the Wild. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (Rochester, New York, USA) *(ASSETS '14)*. Association for Computing Machinery, New York, NY, USA, 123–130. https://doi.org/10.1145/2661334.2661362

[52] Martez E. Mott and Jacob O. Wobbrock. 2019. Cluster Touch: Improving Touch Accuracy on Smartphones for People with Motor and Situational Impairments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300257

[53] Maia Naftali and Leah Findlater. 2014. Accessibility in Context: Understanding the Truly Mobile Experience of Smartphone Users with Motor Impairments. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (Rochester, New York, USA) *(ASSETS '14)*. Association for Computing Machinery, New York, NY, USA, 209–216. https://doi.org/10.1145/2661334.2661372

[54] C Neece, LL McIntyre, and R Fenning. 2020. Examining the impact of COVID-19 in ethnically diverse families with young children with intellectual and developmental disabilities. *Journal of Intellectual Disability Research* 64, 10 (2020), 739–749.

[55] Shuo Niu, Li Liu, and D. Scott McCrickard. 2014. Tongue-Able Interfaces: Evaluating Techniques for a Camera Based Tongue Gesture Input System. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (Rochester, New York, USA) *(ASSETS '14)*. Association for Computing Machinery, New York, NY, USA, 277–278. https://doi.org/10.1145/2661334.2661395

[56] Lílian Fernanda Pacheco, Matias Noll, and Carolina Rodrigues Mendonça. 2020. Challenges in teaching human anatomy to students with intellectual disabilities during the Covid-19 pandemic. *Anatomical Sciences Education* 13, 5 (2020), 556–557.

[57] Neena Pandey, Abhipsa Pal, et al. 2020. Impact of digital surge during Covid-19 pandemic: A viewpoint on research and practice. *International Journal of Information Management* 55 (2020), 102171.

[58] Mariah Papy, Duncan Calder, Ngu Dang, Aidan McLaughlin, Breanna Desrochers, and John Magee. 2019. Simulation of Motor Impairment With "Reverse Angle Mouse" in a Head-Controlled Pointer Fitts' law Task. In *The 21st International ACM SIGACCESS Conference on Computers and Accessibility* (Pittsburgh, PA, USA) *(ASSETS '19)*. Association for Computing Machinery, New York, NY, USA, 545–547. https://doi.org/10.1145/3308561.3354623

[59] Kim Parker, Juliana Menasce Horowitz, and Rachel Minkin. 2021. *How Coronavirus Has Changed the Way Americans Work*. Pew Research Center. https://www.pewresearch.org/social-trends/2020/12/09/how-the-coronavirus-outbreak-has-and-hasnt-changed-the-way-americans-work/

[60] Diogo Pedrosa, Maria da Graça Pimentel, and Khai N. Truong. 2015. Filteryedping: A Dwell-Free Eye Typing Technique. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI EA '15)*. Association for Computing Machinery, New York, NY, USA, 303–306. https://doi.org/10.1145/2702613.2725458

[61] Diogo Pedrosa and Maria da Graça C. Pimentel. 2014. Text Entry Using a Foot for Severely Motor-Impaired Individuals. In *Proceedings of the 29th Annual ACM Symposium on Applied Computing* (Gyeongju, Republic of Korea) *(SAC '14)*. Association for Computing Machinery, New York, NY, USA, 957–963. https://doi.org/10.1145/2554850.2554948

[62] Dharani Perera. 2005. Voice Recognition Technology for Visual Artists with Disabilities in Their Upper Limbs. In *Proceedings of the 17th Australia Conference on Computer-Human Interaction: Citizens Online: Considerations for Today and the Future* (Canberra, Australia) *(OZCHI '05)*. Computer-Human Interaction Special Interest Group (CHISIG) of Australia, Narrabundah, AUS, 1–6.

[63] Melissa Quek, Daniel Boland, John Williamson, Roderick Murray-Smith, Michele Tavella, Serafeim Perdikis, Martijn Schreuder, and Michael Tangermann. 2011. Simulating the Feel of Brain-Computer Interfaces for Design, Development and Social Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 25–28. https://doi.org/10.1145/1978942.1978947

[64] Mary Rice and Kelsey Oritz. 2020. Perceptions of Accessibility in Online Course Materials: A Survey of Teachers from Six Virtual Schools. *Journal of Online Learning Research* 6, 3 (2020), 245–264.

[65] Andreia Sias Rodrigues, Vinicius Kruger da Costa, Rafael Cunha Cardoso, Marcio Bender Machado, Marcelo Bender Machado, and Tatiana Aires Tavares. 2017. Evaluation of a Head-Tracking Pointing Device for Users with Motor Disabilities. In *Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments* (Island of Rhodes, Greece) *(PETRA '17)*. Association for Computing Machinery, New York, NY, USA, 156–162. https://doi.org/10.1145/3056540.3056552

[66] Lucas Rosenblatt, Patrick Carrington, Kotaro Hara, and Jeffrey P. Bigham. 2018. Vocal Programming for People with Upper-Body Motor Impairments. In *Proceedings of the Internet of Accessible Things*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3192714.3192821

[67] David Rozado, Jason Niu, and Martin Lochner. 2017. Fast Human-Computer Interaction by Combining Gaze Pointing and Face Gestures. *ACM Trans. Access. Comput.* 10, 3, Article 10 (Aug. 2017), 18 pages. https://doi.org/10.1145/3075301

[68] Malik Sallam. 2021. COVID-19 vaccine hesitancy worldwide: a concise systematic review of vaccine acceptance rates. *Vaccines* 9, 2 (2021), 160.

[69] Cory Stieg. 2020. *Is it safe to have family or friends in your Covid-19 'bubble'? What you need to know*. CNBC. https://www.cnbc.com/2020/06/27/what-is-a-covid-19-bubble-and-how-to-do-it-safely.html

[70] Abida Sultana, Samia Tasnim, Md Mahbub Hossain, Sudip Bhattacharya, and Neetu Purohit. 2021. Digital screen time during the COVID-19 pandemic: A public health concern. *F1000Research* 10, 81 (2021), 81.

[71] Chun-Hua Tsai, Yue You, Xinning Gui, Yubo Kou, and John M. Caroll. 2021. Exploring and Promoting Diagnostic Transparency and Explainability in Online Symptom Checkers. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (accepted)* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–18. https://doi.org/10.1145/3411764.3445101

[72] "U.S. Census Bureau Reports" 2012. *Nearly 1 in 5 People Have a Disability in the U.S., Census Bureau Reports*. "U.S. Census Bureau Reports".

[73] Stephen Uzor, Jason T. Jacques, John J Dudley, and Per Ola Kristensson. 2021. Investigating the Accessibility of Crowdwork Tasks on Mechanical Turk. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 381, 14 pages. https://doi.org/10.1145/3411764.3445291

[74] Radu-Daniel Vatavu and Ovidiu-Ciprian Ungurean. 2019. *Stroke-Gesture Input for People with Motor Impairments: Empirical Results &; Research Roadmap*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300445

[75] World Health Organization 2021. *Coronavirus disease (COVID-19) advice for the public*. World Health Organization. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

[76] World Health Organization 2021. *COVID-19 vaccines*. World Health Organization. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/covid-19-vaccines

[77] World Health Organization 2021. *Disease Outbreak News (DONs)*. World Health Organization. https://www.who.int/emergencies/disease-outbreak-news

[78] World Health Organization 2021. *Tracking SARS-CoV-2 variants*. World Health Organization. https://www.who.int/en/activities/tracking-SARS-CoV-2-variants/

[79] Ye Yuan, Jan Cao, Ruotong Wang, and Svetlana Yarosh. 2021. Tabletop Games in the Age of Remote Collaboration: Design Opportunities for a Socially Connected Game Experience. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 436, 14 pages. https://doi.org/10.1145/3411764.3445512

[80] Qiao Zhang, Shyamnath Gollakota, Ben Taskar, and Raj P.N. Rao. 2014. Non-Intrusive Tongue Machine Interface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 2555–2558. https://doi.org/10.1145/2556288.2556981

[81] Xiaoyi Zhang, Harish Kulkarni, and Meredith Ringel Morris. 2017. Smartphone-Based Gaze Gesture Communication for People with Motor Disabilities. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 2878–2889. https://doi.org/10.1145/3025453.3025790

[82] Yun-Hong Zhang, Ying-Bao Yang, Tai-Jie Liu, Yi-Lin Chen, and Chao-Yi Zhao. 2017. Comparative Study on Visual Fatigue and Comfort of Different Types of Polarized Light LCD Mobile Phone Screen. In *Proceedings of the 2017 International Conference on Wireless Communications, Networking and Applications* (Shenzhen, China) *(WCNA 2017)*. Association for Computing Machinery, New York, NY, USA, 110–115. https://doi.org/10.1145/3180496.3180616

[83] Zoom 2021. *Zoom*. Zoom. https://zoom.us/