RESEARCH BRIEF

Accessibility, Usability, and Social and Cultural Acceptance of Next-Generation Wireless Devices: Initial Findings from Focus Group Research[1]

Volume 2018, Number 18-01, December 2018

Executive Summary

This research brief summarizes findings from focus groups on accessibility, social appropriateness, and cultural acceptability of wireless technology use among individuals with disabilities. The research was conducted by the Rehabilitation Engineering Research Center on Wireless Inclusive Technologies (Wireless RERC). A total of 41 individuals with disabilities who use smartphones, wearables, and "smart home" devices participated in the study. Nine focus groups took place between November 2017 and April 2018, with two follow-up focus groups in early June 2018 probing usability issues.

Opportunities and facilitators associated with next-generation wireless devices for users with disabilities include: 1) voice control as an alternative means of input, particularly for users who may have difficulty accessing a touchscreen, such as people who are blind or individuals with limited dexterity or mobility, 2) effectiveness of intelligent assistants for information or control of wirelessly connected "smart" devices such as light bulbs or thermostats, 3) potential cost effectiveness of "smart home" devices compared to legacy home automation solutions for individuals with disabilities, 4) potential usefulness of wearables for input and output, as well as for simplifying everyday tasks such using point-of-sale payment systems, 5) continued ability to control information streams through customized push notifications, such as linking a tone or vibration cadence to a specific user or group of users or application (i.e. e-mail, social media, news outlet), and 6) continued integration of established smartphone technologies and apps with next-generation devices for some users with disabilities. **Barriers and unmet needs** related to these technologies include: 1) perceived lack of integration between devices and the supporting platform ecosystems, 2) software and hardware accessibility problems that are often caused by system updates, 3) continued limitations in battery life and their effect on devices for accessibility, 4) uncertainty about usage of consumer data, data privacy and security, 5) concerns about dependence on specific technologies, and 6) limitations of voice control and intelligent agents as accessible features for some users, such as individuals who are Deaf or people with communication disabilities. **Preliminary recommendations** from this research include: 1) the ongoing need for device interoperability, 2) adoption of evolutionary design perspectives to go beyond simple device accessibility to focus on cross-disability usability, 3) design parameters and policies that balance

[1] Report authors: Nathan W. Moon, Paul M.A. Baker, Kenneth Goughnour

need to collect data for operability with the desire of users to protect their privacy, and 4) the continued need for more robust user testing involving users with disabilities for usability and interoperability.

Key Findings: Opportunities and Facilitators

Intelligent Agents and Voice Control

The emergence and continued refinement of voice control, coupled with intelligent agents, may represent the single greatest facilitator for usability among many, but not necessarily all, users with disabilities. Voice-based control for both Apple iOS and Google Android-based smartphones, as well as "smart speakers" such as Amazon Echo with Alexa, Apple HomePod with Siri, and Google Home with Google Assistant, was the most commonly cited feature used by individuals with both vision-related disabilities and dexterity-related disabilities. Users reported use of smartphone intelligent agents, including their ability to provide calendar and scheduling information, weather updates, and location and navigation-based information for wayfinding, as essential features.

Similarly, users with limited mobility and dexterity, including individuals with spinal cord injuries who are quadriplegics and those with multiple sclerosis and arthritis, were adopters of IoT smart home technologies that represent, in essence, the next generation of home automation. Most of these users were enthusiastic about smart speakers such as the Amazon Echo and Dot, Google Home, and Apple HomePod for controlling their home environment, through devices such as Philips Hue smart lightbulb and Ecobee and Nest smart thermostats. Others reported the use of Wi-Fi enabled plugs, remote controlled locks, and home cameras as an additional level of home control.

When probed about the use of voice input intelligent agents in wearables and smart home technologies more generally, users' perceptions often were linked to their prior experiences with dictation software, particularly Dragon Speaking Naturally. In very few instances did users' note that intelligent agents such as Alexa and Siri understood them better than traditional, dedicated dictation software. Some users also commented on the relative affordability of these devices compared to specialized home automation systems they may have owned in the past.

Wearables

Regarding wearables, smart watches were the most frequently mentioned devices. Despite some accessibility challenges, successful adopters of smart watches such as the Apple Watch and Samsung Gear noted that these wearables offered several advantages. Most commonly, the watch's connection to a smart phone means that users do not need to have their phone out in order to take a phone call. As one participant with dexterity limitations observed, "if I want to see who's calling, I can always check [my smartwatch] before I answer, instead of having to pull the phone all the way out…[it's just] an easier way of accessing." For one Apple Watch user with a spinal cord injury, there were distinct advantages related to near field communication (NFC). She noted that it was easier for her to make payments using Apple Pay than by handling cash or cards in a transaction that required more movements, greater control, and the potential for physical pain.

Blind users also noted the convenience and accuracy of having specific, assigned vibration cadences delivered through a smart watch. For these users, they extended the functionality of their smartphones, such as the ability to receive phone calls, text messages, notifications, and other streams of information, and seen as more of a convenience but not necessarily as assistive technologies, per se.

High cost was perhaps the greatest challenge to the adoption of the devices. Users of specialized wearables such as the Aira service, either through Google Glass or Aira's Horizon headset, did note the greater affordances and accessibility that such devices offered as assistive technologies.

Continued Importance of Smartphones

Despite the growing adoption of IoT-enabled devices such as wearables and "smart home" technologies, they remain largely tied to smartphones in terms of integration and platform. Frequently, users who choose Apple iOS or Google Android-based phones because of accessibility, usability, or other factors, tend to base their decisions for wearables and other devices based on their experience with smartphones and a given ecosystem. For example, anecdotal evidence suggests that adoption of the Apple Homekit is more likely by users who already used other Apple devices, and adoption of Google Home has been linked to users familiar with Android-based devices. One notable exception is the Amazon Echo, which has been used either as a standalone device or in conjunction with IoT-enabled devices in the home. The availability, accessibility, and usability of apps associated with such devices is also a factor in their adoption, as is the perceived usability of these apps on a given mobile platform such as iOS or Android.

Key Findings: Barriers and Unmet Needs

Integration between Devices and Platforms

Despite reporting positive experiences overall, there remain a number of usability concerns. Perhaps the greatest challenge among this group of users was **interoperability**. Because of their limited mobility and dexterity function, many users reported using the voice control function through either a smart speaker or mobile phone using an intelligent agent such as Alexa or Siri. As previously noted, if voice control was not an option or did not work, the devices were inaccessible for this group despite alternate modes of input such as a smartphone app. For example, one user noted that the Ecobee was inaccessible to her because Siri could not recognize her commands and she could not utilize the app because of limited hand control.

Usability Considerations: Device Setup and Cognitive Load

In addition to the first nine focus groups that probed, in part, on perceptions of accessibility and usability based on function (i.e. vision, hearing, and mobility), the RERC conducted two usability focus groups *specifically* on the accessibility and usability of next-generation wirelessly connected devices. Drawing upon the principles for heuristic (i.e. usability) evaluations, the first focus group examined wearables and the second one investigated "smart home" technologies.[2]

When thinking about smart home technologies, a frequently recurring observation was that the devices are difficult to setup. For users who are blind, this frequently was an outright accessibility challenge. For this individual, trial and error was a common setup experience, which suggests low usability of the workflow, and one which is relatively easy to address. During power outages and consequential loss of Internet connection, the same user also relied on trial and error to restart the device. Individuals who were blind also noted similar experiences when attempted to set up smart

[2] Principles established by Molich & Nielson 1990; Nielson 1994; Gerhardt-Powals 1996; and Weinschenk & Barker 2000 guided the development of a protocol for usability studies, as put forth by Virzi (1992) and Nielson (1994).

thermostats. As one user of the Nest Thermostat noted: “Companies try to accommodate disabled people. But you still have to have somebody sighted to set it up.” This user largely had a positive experience once that initial setup had been completed. In this sense, we can think of device use as lying along a gradient with simple *accessibility* on one end and device *usability* on the other. Usability challenges were common to other groups, as well. Individuals with dexterity impairments noted their inability to use the input ring on the original Echo. As long as there was some alternate means of control, they generally reported a positive experience. Buttons were also cited as a major cause of concern. Users with limited mobility and dexterity also noted that moving and placing devices themselves may be challenging due to the size and weight of the object.

In pointing out the potential of intelligent assistants for enabling greater independence, several users mentioned the problem of remembering the specific command syntax for Alexa skills, for example. One user had downloaded 47 skills for Alexa, which comparable to apps, but noted her inability to remember the correct commands to open them, and writing down commands undermined the ease-of-use. Rather than outright accessibility issue, this and similar challenges related to cognitive load suggests that the user interface may benefit from usability testing to improve the experience for all users, including individuals without disabilities.

Limitations of Voice Input and Output

For blind users, user interface input and output (IO) appear to be more intrinsically linked than for other user groups. Many users indicated their preference for voiceover, where the OS “reads” text or other content in the form of text-to-speech. This output can also facilitate input on a smartphone by telling the user which button they currently have selected. However, it also requires that the voiceover be accurate, in the sense that it correctly “reads” out the text or button. Users occasionally noted that voiceover sometimes could be inaccurate. Successful use of voiceover also may be complicated by latency or other slowdowns on the device, which are specific either to the OS or to an app, for which periodic restarts may be required. In fact, for users who are blind, an app that does not support voice over may be considered totally inaccessible.

Degree of control or customizability was a factor in voice control. For devices such as the Philips Hue, Nest, and Ecobee, the smartphone app provided more options for user settings. By contrast, voice control, which was deemed important for this group, did not provide as many options. Another user noted that she appreciated being able to turn her Philips Hue lights on and off through her Alexa-enabled control. However, she also reported that features such as the ability to specify which, from among several, lightbulbs to turn on or off, or dimming control, were not available to her through voice and she could not utilize the app in the smartphone. This case suggests a broader issue of user perception of the features and capabilities of technologies. According to documentation from Philips, this capability exists for Amazon Echo devices.[3] Thus voice input devices may be capable of more than users believe is the case, suggesting the need for better or more expanded help/guidance functions. Another possibility might be the need menu item, or an item that list capacities installed or available.

Ongoing Challenges of System Updates and Battery Life

[3] https://www2.meethue.com/en-us/friends-of-hue/amazon-alexa

A consistent issue raised across all of the focus groups was the problem of updates to the device operating systems (OS) and apps that had subsequent effects on device accessibility. Users frequently noted that a previously accessible app or feature could be "broken" following a routine operating system update. While users developed a variety of strategies for dealing with this issue, ranging from simply reading and memorizing all of the documentation to relying on online communities; ultimately, simple trial and error was the main way of determining changes to accessibility following updates. Users mentioned developing a methodical approach for discerning these changes.

In a similar vein, battery life was consistently cited as a concern for many users with disabilities, which was related in large part to their reliance upon the device and constant use of apps for accessibility, such as wayfinding or communication. This suggests that a possible approach for device developers was to test update usability with end-users as part of the development cycle. One other major accessibility issue encountered by individuals with mobility and dexterity-related disabilities involved the matter of wireless charging and the ability or inability to grasp and manipulate plugs and cords on their devices. For one user, the need to plug in the Samsung Gear and the difficulty associated in using the charging cable was the major reason for abandonment. Other users noted that plugs or, alternatively, options for wireless charging are major factors for adoption of specific wireless devices. Thus, the problem here was not so much inaccessibility of a specific device, but the usability of the whole technological (workflow) system.

Data Privacy and Security

Participants who identified as blind reported use of a number of strategies to ensure their privacy. Many users noted their use of the "screen curtain" feature to create a black or otherwise blank screen so that nearby individuals could not see their screen. Others participants deliberately sped the voice output to a level fast enough that inexperienced individuals could not understand what was being said. Finally, earphones are used to ensure privacy to minimize need to have their devices in the open.

Concerns over privacy extend to smart home devices, as well. Despite being faster, more convenient, and potentially more accurate, one user noted that depending on the context and setting, particularly when there are caregivers present, voice control offers less privacy than typing a command, message, or some other form of communication. For many participants, particularly those with acquired mobility-related disabilities from spinal cord injuries, there frequently is a trade-off between accessibility and privacy. A number of participants expressed concerns about privacy of smart home devices, with several noting the perceived lack of privacy as a reason for not adopting these technologies. Another user, a quadriplegic with limited upper limb function who uses an Apple Watch, expressed concerns regarding the Apple Pay system for making transactions. However, the growing usefulness of the device in her everyday life, discussed below, mediated those concerns somewhat.

Technology Dependence

Concerns about over dependence on technology were frequently voiced by users. For example, blind users noted that while apps such as Uber have transformed their ability to travel locally, it remained necessary to know how to call a taxi in case there were issues with the app. Another user noted the importance of remembering key telephone numbers. Another user, reflecting on his use of Alexa, observed, "I think that it's useful. I think it's good for our lives. I just felt that...even when it's unnecessary to move toward more technology, and I don't want to go too far into it, but I just think that it affects us…how part of what makes us healthy is getting up and doing some things and moving around. But when we give it all to these devices that do it for us, well then we'll be weaker than we used to be."[4]

Preliminary Recommendations

Wirelessly connected technologies have been incorporated into a new generation of devices ranging from wearable computing devices (wearables) to physical objects such as appliances constituting an "Internet of Things" (IoT) with applications and uses for people with disabilities.[5] The design of these technologies remains open and unfixed, thus presenting an opportunity for the participation of people with disabilities alongside designers, developers, and manufacturers.[6] A socially and culturally sensitive design process may proactively ensure acceptance of these technologies and help counter their abandonment or outright rejection.[7] For people with disabilities, community engagement, participation and self-determined living enhanced by wireless technologies have assumed a new importance.[8]

As use of wireless devices extends beyond smartphones to include next-generation wirelessly connected devices, users continue to note the need for cross-device and cross-platform compatibility. This suggests that an opportunity exists to explore the use of design at the ecosystem rather than devices level. Here the question is, can accessibility at the device level be enhanced by explore the role of usability at the system or platform level?

It was important for the participants to be able to control all their smart devices and technologies from one device. Regardless of specific accessibility and usability needs, a common theme remains the ability to customize technologies to individual preferences and to make more user friendly. A number of participants observed that they enjoyed the iPhone's ability to customize auditory and haptic alerts to each of their contacts, particularly as a way of managing large streams of data. Increased

---

[4] Shepherd Center, November 30, 2017, Participant 6, p. 14-15.

[5] Domingo, M. C. (2012). An overview of the Internet of Things for people with disabilities. *Journal of Network and Computer Applications*, *35*(2), 584-596; Nussbaum, G. (2006). People with disabilities: assistive homes and environments. In *Computers Helping People with Special Needs* (pp. 457-460). Heidelberg: Springer Berlin.
[6] Baker, P.M.A., Gandy, M., & Zeagler, C. (2015). Innovation and Wearable Computing: A Proposed Collaborative Policy Design Framework. *IEEE Internet Computing*. Sept.-Oct. 2015 (2015), 18 – 25.
[7] Scherer, M. J. (2005). Assessing the benefits of using assistive technologies and other supports for thinking, remembering and learning. *Disability and rehabilitation*, *27*(13), 731-739; Parette, H. P., & Brotherson, M. J. (2004). Family-centered and Culturally Responsive Assistive Technology Decision Making. *Infants & Young Children*, *17*(4), 355-367; Parette, H. P., Huer, M. B., & Scherer, M. (2004). Effects of acculturation on assistive technology service delivery. *Journal of Special Education Technology*, *19*(2), 31; Crabtree, A., Hemmings, T., Rodden, T., Cheverst, K., Clarke, K., Dewsbury, G., & Rouncefield, M. (2003, November). Designing with care: Adapting cultural probes to inform design in sensitive settings. In *Proceedings of the 2004 Australasian Conference on Computer-Human Interaction (OZCHI2004)* (pp. 4-13).
[8] Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer networks*, *54*(15), 2787-2805; Jara, A. J., Lopez, P., Fernandez, D., Castillo, J. F., Zamora, M. A., & Skarmeta, A. F. (2014). Mobile discovery: discovering and interacting with the world through the internet of things. *Personal and ubiquitous computing*, *18*(2), 323-338.

customization can allow people to explore new options to interact with the technology and better adapt it to their unique situation. One final desire was a device/technology that combines the best of all the different devices/technologies available. For instance, many people with dexterity disabilities commented on the usability of touchscreen gestures in Android devices, yet appreciated the intuitive nature of Apple devices.

Ensuring device inclusivity and being able to meet the needs of a wider range of users requires that research go beyond just "user needs" to address accessibility expectations, expand technical assistance to reach new consumers with disabilities, and their caregivers. Broadly writ, "usability," as a means to enhance social connectedness and living independence. We contend that such an approach is necessary to comprehend as fully as possible the ways in which next generation technologies are changing how people with disabilities use technology. Based upon previous work by the Wireless RERC, participants in these focus groups discussed two key issues: a) how people with disabilities use these technologies in daily life, with a focus on accessibility, usability, and acceptability of current IoT wireless technologies to determine factors influencing their adoption and use or, alternately, rejection or abandonment, and b) how wireless and smart technologies serve specifically as accommodations for users with disabilities, including unmet needs, latent demands, and user expectations. Future projects will address issues of inclusive/accessible technology design through research, training and dissemination activities that will leverage our findings that can provide critical input to policymakers and other stakeholders.

These research findings have utility beyond simply design inputs. From a policy perspective we conclude that aside from the need for developer/stakeholders to address device interoperability, and simple device accessibility, thought should be given to technological usability with in context, rather than mere interface accessibility. Finally, design parameters should balance the need to collect data necessary for customization and operability with desire of users to protect privacy.

Additional Considerations: By Device

IoT-Enabled Technologies

Specific needs of users often factor into their adoption, use, abandonment, and rejection of these technologies. For example, one user with a spinal cord injury who had used an Ecobee thermostat elaborated that Siri could only recognize a command to run the thermostat in automatic mode. However, this mode has a six (6) degree differential, such as 68 to 74 degrees, which is a large range for an individual with cervical injuries and who may need a more narrow temperature range to regulate body temperature. This user needed a very specific temperature, and the Siri-controlled auto-setting was not ideal, and she could not use the app. As a result, she replaced the Ecobee with a Nest that gave her a greater degree of control through voice.

As previously mentioned, the need for access may intersect with other concerns such as privacy. Elaborating further on a key finding, one user, who is a quadriplegic, noted with regard to voice input, "When it comes to the texting, I don't like to speak my words out loud. I don't know, I am weird like that. Even if I am the only one in the room, I want some privacy with my thoughts, so a lot of my text messages, I will just rather type them than say them out loud."[9] Reflecting on his use of Amazon Echo,

[9] Shepherd Center, November 30, 2017, Participant 6, p. 13.

this participant mentioned, "Normally, I have a caregiver around. There's usually always somebody around… So, it's just ingrained to me to not want to speak out my thoughts out loud…I don't mean that [in a] conspiracy theory way…but there's always the ability to hack into this."

Smartphone Technologies

Privacy continues to extend to smartphone technologies as well. As one participant who is mostly blind (with some very limited visual acuity and light perception) noted:

I have to walk a fine line when I'm in public, because I do visually access my phone sometimes [by holding it very close to my eyes]. People say directly to me, "Oh, you're not blind, you're faking it." If I'm on the train, I usually use more voice over, just to not have to deal with people. I'll turn voice over on, and I'll turn the screen curtain on, and then I use the voice over version of scribble, so they have a handwriting feature, where I can just handwrite on the screen, just like on my [Apple Watch]. I'll use that sometimes, just to send out a quick message. I dictate sometimes, but yeah there are privacy concerns, too. That's why I have the headphones on, but also when I'm using magnification, I'm well aware that people see more than me, and sometimes people will be looking over my shoulder or if I'm reading something on the kindle app. Sometimes, somebody says "oh wait I wasn't done" when I'm reading, so that's awkward. But that's one of the reasons for using voice over with the screen curtain on, so that people can't look over your shoulder, I can listen to my emails or whatever it might be.[10]

Another user, with acquired blindness (and who is not a Braille user), observed of individuals with refreshable Braille displays, "Even though I had a progressive eye condition where I would be blind one day…they didn't teach [Braille] to me. I learned it more as an adult, but I'm really slow at it. I so envy those folks that have the Bluetooth braille displays that they can use with their phones, because they have the ultimate privacy."[11]

Additional Considerations: By Functional Limitation

Blind and Low Vision Users

Among blind users, there was an overwhelming preference expressed for iPhones and iOS-based devices. As one participant noted, "I think the majority of blind people use the iPhone because of the accessibility feature. I have even [participated in] focus groups for the [Samsung] Galaxy, trying to help understand what they can do [for Android's] accessibility compared to the Apple phones… It's the lag time and also the talk back feature." As a result, users described being part of a larger, inclusive "community" able to communicate by taking advantage of Apple-specific features such as FaceTime as a way to reduce cellular data usage (cited as a concern among users with disabilities). These users cited such features as the fact that the accessibility features were a top-level menu option, which made them easier to find and access. Users also noted the customizability of those features. As one participant noted, "When I first became blind, I was an Android user, so I was told to try the Apple. I turn[ed] on the accessibility. Once I got to voice over, I played around and added things and customized it myself…to how I like it. I like touch typing, I don't like the double tap. I type normally [unlike other blind users]."

[10] AMAC, December 6, 2017, Participant 1, pp. 17-18.
[11] AMAC, December 6, 2017, Participant 2, p. 19.

Setup was mentioned as the greatest challenge to adoption and use for blind users specifically. One user of the Amazon Echo who is blind observed that use of colored lights as a key indicator for setup, posed a major barrier for him:

> During the set up I would keep pressing the button. It would say wait until the orange ring, of course I couldn't see the orange ring and so I would just keep pressing. I didn't know which buttons to press…[Another participant noted] there's no sound to alert when that happens…[Original participant] I did do it, but it took me a long while, because I just had to keep pressing the button…I would wait, after I would press a button, I would wait 5-10 minutes and then I would say Alexa and then she would say Hi.

Use context was cited as a critical factor by blind users when deciding on the most appropriate form of input. For example, one participant noted that "It depends on what I'm doing on the phone. If I'm sending a long email, I hook myself up to the wireless keyboard. It's faster that way. I use voice over a lot too, but sometimes it comes out all kinds of wrong."[12] Others commented that the length of message or specific application as a major factor in whether to use voice control (i.e. dictation), touchscreen keyboard supported by voiceover, or an external device (i.e. conventional keyboard) for input. Despite a possible tension between voiceover-onscreen keyboard vs. voice command, many users indicated their use of both depending upon the application, appropriateness, and need.

People with Mobility and Dexterity Limitations

There were greater concerns regarding the value of *wearables* for this group of users, owing in large part to their limited hand control and decreased sensitivity for vibro-tactile feedback. Several participants noted that they either owned or had used wearables such as the Fitbit, Apple Watch, or Samsung Gear. A number of individuals with spinal cord injuries experienced neuropathy, particularly in their fingertips. As a result, they indicated that they used a stylus instead of their fingertips for using smartphone touchscreens. However, the smaller screens for smartwatches make them more difficult to use among these users, and their use is complicated further by a lack of fine motor control for using the smaller screens of smartwatches. An Apple Watch user commented that it offered some, but not complete, functionality: "It has so much functionality, but it's such a small screen that it defeats you from even trying to use it for [health related functions, such as heartrate monitoring]."

In spite of these accessibility challenges, successful adopters noted that their smart watches offered several advantages. Most commonly, the watch's connection to a smart phone means that they do not need to have their phone out in order to take a phone call. As one user observed, "if I want to see who's calling, I can always check [my smartwatch] before I answer, instead of having to pull the phone all the way out…[it's just] an easier way of accessing." For one user who owned an Apple Watch, there were distinct advantages related to near field communication (NFC). In spite of concerns she mentioned regarding data security, she noted that it was easier for her to make payments using Apple Pay than by handling cash or cards in a transaction that required more movements, greater control, and the potential for physical pain.

[12] CVI, February 21, 2018, Participant 1, P. 3.

Among non-adopters, the inability to sense vibrations or other sensations on the skin due to nerve damage, and the dexterity needed to use the devices represented a use barrier. For one user, both of these challenges were summarized as:

> Vibration is only good if you can feel it… My right hand has more feeling, I don't wear watches on my [left side]. I have no feeling from my chest down…If you have to touch buttons, my right hand is more reliable that my left… If I need to feel, I would have to put it on my right. Then I wouldn't be able to do the buttons accurately.

For this particular user with a spinal cord injury, there were differences between each arm, with varying degrees of sensation and dexterity. Given that wearables require both arms—one for sensation of the vibration and the other to carry out functions by hand, usability may be complicated.

Focus group participants suggested several possibilities for increasing the potential usability of wearables. One might be utilizing bone-conduction as an alternative for relying on skin sensation for vibration output. Another possibility would be placement of a wearable on another part of the body, such as a pendant worn around the neck, *provided that* the user had sensation in that part of the body for such output. A different modality might be used for input. Hence, for such users, input and output may need to be separated in order to account for differing levels of sensation and function in the body. Furthermore, it is important to remember that such functionality is highly individual to the user.

People who are Deaf or Hard of Hearing

Among users who are Deaf, cultural factors were frequently identified as the main barriers for technology adoption and use. A common sentiment expressed among this community was the potential of technology to facilitate communication among users whose first language is ASL. Camera-enabled devices, including laptops, tablets, and smartphones, along with communication apps such as FaceTime for Apple iOS or IMO Messenger or Marco Polo for Android-based phones. Users also reported the use of such features as private messaging on Facebook, which enables users to video record messages in ASL and to leave them for one another as a form of asynchronous communication. However, users cited two challenges.

First, they noted the issue of interoperability. Participants who are Deaf noted their use of video-based services such as FaceTime or Skype for communicating, however, they expressed frustration at not being able to use preferred platform such as FaceTime when the other party was not an iPhone user. This challenge is most pronounced when using video relay services (VRS), such as Sorenson, Purple, or Convo, in which participants noted that users of different services frequently have difficulty communicating with one another.

A second concern expressed by users who are Deaf are the ways in which technologies may undermine the goal of communication. For example, one participant related an example in which he was a patient in the hospital and attempted to use this mobile phone's Notes app as a way to communicate with his physician. He previously had used the Notes app to communicate with his longtime physician, which he described as "beautiful…great…very smooth." However, he encountered difficulties with subsequent physicians:

> The doctor was hesitant and then after a while he left and he came back and he brought a laptop and brought in the Video Relay interpreter service which wasn't really what I wanted

> because this is infamous for having a frozen screen…That screen always freezes up, which I was disappointed. I just wanted to do the texting back and forth but the doctor left and came back with the screen….So then you have this fuzzy screen, it's hard to see, and he was trying to talk closer to the screen, turn up the volume, trying to make it go smoother, but the screen kept freezing.[13]

In the end, the problem was summarized as "too much technology." Users in other focus groups expressed similar sentiments about video relay interpreting.

Regarding wireless technologies themselves, users noted their use of vibration cadences on their smartphones and other mobile devices as a way of distinguishing between contacts who are trying to reach them. One interesting use among this group was the use of different cadences to distinguish between text messages, which might be checked as convenient, or Facebook notifications, which could indicate the need for more immediate attention. Elaborating further on notifications, users differed greatly in their preferences. Some users noted that they preferred light notifications, especially for emergencies. Some also referenced Sorenson's use of different light signals as a possible model for communicating streams of information. When asked about vibration, one user noted his sensitivity to vibrations, which feel like "electric shocks," explaining that "some Deaf people have very sensitive feeling." Another user noted the problem of phantom vibrations: "You feel that vibration even without the phone. It's something I've noticed. So that's why I stopped using that, because I would get the vibration even when I didn't have the phone on my person, as well." However, other users preferred the more immediate prompting that vibrations provide, as well as a need to not always be within visual contact of their devices. One user commented on her use of an Apple Watch as a more effective means of communication specifically because of its vibration-based notifications as a means of output.

When queried about IoT-enabled devices, particularly smart home technologies, participants who are Deaf observed interest in the devices, but also noted that their frequent reliance on voice input and audio output potentially undermines their utility for this group of users. In general, there seems to be lagging awareness about the devices, and, for some users, slight indifference toward them:

> You know, the Echo that can speak? Or Alexa or whatever….Okay, so I wish I had one of those but I wouldn't be able to hear it but I wish that it could be captioning…whatever she's saying when you speak to it, it would come back in some kind of screen that I could read.

Regarding its potential as an assistive technology, the participant elaborated, "Well, oh, yes, for blind, sure, but not for someone with hearing loss. I need to read the captioning always to see what's going on." While Amazon had introduced a screen-based version of Echo around the time of this focus group, another participant weighed on the matter of individuals who are Deaf but who may not necessarily know English, thus further reducing the usefulness of the technology for people whose primary language is ASL and who may not benefit from captions: "Will it have an interpreter, right, with the Deaf-first language?"

About the Wireless RERC

The Rehabilitation Engineering Research Center for Wireless Inclusive Technologies (Wireless RERC), is funded by developed under a grant from the National Institute on Disability, Independent

[13] Georgia Centers for the Deaf and Hard of Hearing, March 28, 2018, 10 a.m., Participant 1, p. 20.

Living, and Rehabilitation Research (NIDILRR grant number 90RE5025-01-00). NIDILRR is a Center within the Administration for Community Living (ACL), Department of Health and Human Services (HHS). The contents of this publication do not necessarily represent the policy of NIDILRR, ACL, HHS, and you should not assume endorsement by the Federal Government.

For more information about the Wireless RERC, please visit us on the web at: http://www.wirelessrerc.org/.

Wireless RERC Focus Groups

1. Center for the Visually Impaired (CVI), Atlanta, Georgia, November 28, 2017, 10 a.m.
2. Center for the Visually Impaired (CVI), Atlanta, Georgia, November 28, 2017, 1 p.m.
3. Shepherd Center Rehabilitation Hospital, Atlanta, Georgia, November 30, 2017, 1 p.m.
4. AMAC Accessibility and Georgia Tools for Life, Georgia Institute of Technology, Atlanta, Georgia, December 6, 2017, 3 p.m.
5. Shepherd Center Rehabilitation Hospital, Atlanta, Georgia, February 7, 2018, 1 p.m.
6. Center for the Visually Impaired (CVI), Atlanta, Georgia, February 21, 2018, 10 a.m.
7. Center for the Visually Impaired (CVI), Atlanta, Georgia, February 21, 2018, 1 p.m.
8. AMAC Accessibility and Georgia Tools for Life, Georgia Institute of Technology, Atlanta, Georgia, March 2, 2018, 10 a.m.
9. Georgia Centers for the Deaf and Hard of Hearing (GCDHH), Decatur, Georgia, March 28, 2018, 1 p.m.
10. Center for Advanced Communications Policy (CACP), Georgia Institute of Technology, Atlanta, Georgia, June 6, 2018, 1 p.m.
11. Center for Advanced Communications Policy (CACP), Georgia Institute of Technology, Atlanta, Georgia, June 7, 2018, 1 p.m.

Selected References

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer networks*, *54*(15), 2787-2805.

Baker, P.M.A., Gandy, M., & Zeagler, C. (2015). Innovation and Wearable Computing: A Proposed Collaborative Policy Design Framework. *IEEE Internet Computing*. Sept.-Oct. 2015 (2015), 18 – 25.

Domingo, M. C. (2012). An overview of the Internet of Things for people with disabilities. *Journal of Network and Computer Applications*, *35*(2), 584-596.

Gerhardt-Powals, J. (1996). Cognitive engineering principles for enhancing human-computer performance. *International Journal of Human-Computer Interaction*, *8*(2), 189-211.

Jara, A. J., Lopez, P., Fernandez, D., Castillo, J. F., Zamora, M. A., & Skarmeta, A. F. (2014). Mobile discovery: discovering and interacting with the world through the internet of things. *Personal and ubiquitous computing*, *18*(2), 323-338.

Molich, R., & Nielsen, J. (1990). Improving a human-computer dialogue. *Communications of the ACM, 33*(3), 338-348.

Nielsen, J. (1994). *Usability engineering*. San Diego, CA: Academic Press.

Nussbaum, G. (2006). People with disabilities: assistive homes and environments. In *Computers Helping People with Special Needs* (pp. 457-460). Heidelberg: Springer Berlin.

Parette, H. P., & Brotherson, M. J. (2004). Family-centered and Culturally Responsive Assistive Technology Decision Making. *Infants & Young Children*, *17*(4), 355-367.

Parette, H. P., Huer, M. B., & Scherer, M. (2004). Effects of acculturation on assistive technology service delivery. *Journal of Special Education Technology*, *19*(2), 31.

Scherer, M. J. (2005). Assessing the benefits of using assistive technologies and other supports for thinking, remembering and learning. *Disability and rehabilitation*, *27*(13), 731-739.

Virzi, R.A. (1992). Refining the test phase of usability evaluation: How many subjects is enough? *Human Factors,* 34(4), 457–468

Weinschenk, S. & Barker, D.T. (2000). *Designing effective speech interfaces*. New York: Wiley.