Wearable Assistive and Augmentative Communication Button

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ABSTRACT

A common problem in the disabled community is the high abandonment rate of assistive technology devices. For the non-verbal, their communication aids are often bulky and the user needs to be seated at a table or settled in a particular place to use it with ease. A wearable assistive/augmentative communication (AAC) button device was developed in conjunction with a cross-platform mobile application in order to explore communication aid capabilities and applications in more mobile settings, such as in therapeutic or recreational sports. Additionally, because we held small size as a distinctive design goal, we were able to somewhat gage where the users might be willing to wear the devices. An initial prototype was completed successfully, along with the Android platform version of the mobile application. After conducting four light user experience tests and an interview with an occupational therapist, it was determined that the project has the potential for a wider range of applications than initially determined, and will be developed further in the future.

INTRODUCTION

It has been estimated by the CDC that 1 in 68 U.S. children have autism [3], and research has shown that as many as 25% of them are non-verbal [10]; for this research, they were the initial target user group. Previously, a pad that could be strapped to your leg and spoke short phrases related to horse therapy was developed by Halley Profita at the University of Colorado Boulder's Computer Science lab. This study expands upon that goal of enabling communication in more mobile environments, with additional requirements calling for a smaller model in order to enable the studying of the device placement and broadening of potential applications.

To explore the idea of what we wanted to make, we brainstormed and came up with the idea of a small button that you could pin anywhere on your clothes. It was determined that it could be developed via a new Sparkfun/Adafruit/Arduino board that has a WiFi module called the ESP 8266. See figure 1 for a size comparison of each board. Considerable time was spent learning about microcontrollers and then programming the specific boards. The PHP pinging webpage was used to store data from the controllers that a mobile app on a phone connected to the internet could download. We decided to use Xamarin Forms because of my familiarity with C# and the

fact that it was cross platform, and could thus be used on a larger variety of smart phones. We found that we could not get the button as small as we had initially wanted mostly due to battery requirements and the board size, but we were still able to make a device that was only slightly larger than an iPod shuffle. After the light user experience testing sessions it was determined that the mobile application's interface could use additional work on its clarity and simplification, but has some promise. We conclude with suggestions for future work and further applications based around the rest of the findings from the user tests and interview with the occupational therapist.
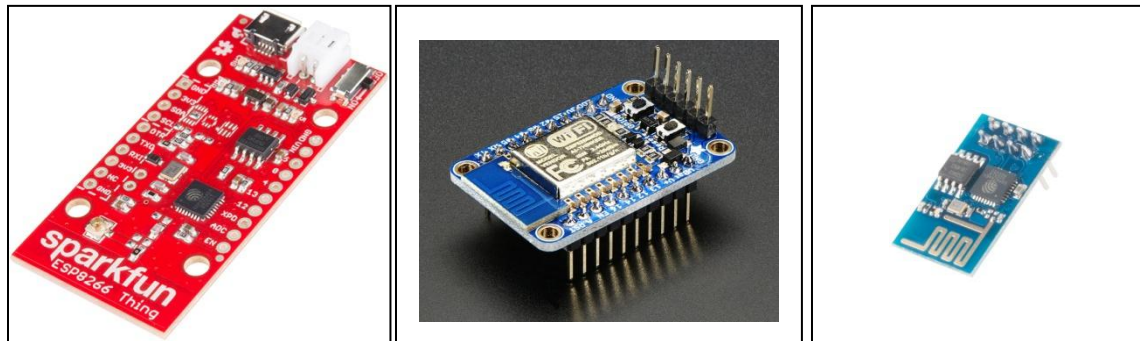

Figure 1. Images of the three boards. The Sparkfun ESP8266 Thing (left), the Adafruit ESP8266 Huzzah (center), and the ESP8266 generic module (right). Although the generic module is smallest, it is harder to program and attaching it to a battery makes it bulkier than the Adafruit board.

RELATED WORK

This research is connected to the study of assistive technology and the relatively new studies of wearable computing and mobile development. This work contributes to the study of human-computer interaction with mobile wearables.

Wearable Assistive Technology

In recent years, wearable computing has gained more attention and commercial investment. The success of products such as the Fitbit and Apple Watch attest to its potential. Some researchers have already started to develop assistive wearable technology with various uses. For example, the GIST [9] and Headlock [5] projects out of the University of Nevada Reno produced wearable navigation aids that help the blind or visually impaired navigate their area and traverse large open spaces. Additionally, the Flutter dress created by Halley Profita at the University of Colorado Boulder senses where loud noises are coming from and indicates the source direction via haptic feedback, an application targeted for the deaf and hard of hearing [12]. On Thingiverse, a hub for sharing 3D printing designs, it was found that creators are designing artificial limbs and other wearable assistive technology for their loved ones or friends and posting their designs for public use [2]. While some projects embed themselves directly into clothing items [7 , 12], we wanted to make a wearable you could ostensibly place anywhere,

allowing for more flexibility and a wider range of activities it could be used in, and provide a way to study where people would be willing to display the technology on themselves.

Mobile Applications and Assistive Technology

People with disabilities are using smart phones just like everyone else, and the platform's power and portability make it a great potential medium to develop assistive applications on. Some prior exploration in this field includes a study in which a smart phone was made more accessible to the blind through the use of screen readers and multi-touch interaction techniques [8]. Another project of note is BraillePlay, a mobile app game that uses vibrating Braille dot patterns in word games that aid in the learning of Braille for kids and their families [11]. VizWiz, another application, used the micro-task market Mechanical Turk on Amazon to provide a service to the blind that would have the person in question take a picture of their environment and record a question they had about it, and send it to the group of workers to be answered for only seven cents [1]. The feedback time was great, averaging only about 2 minutes. The ubiquity of smart phones was used to the project's benefit, and as a convenient way to provide a more robust interface for programming the buttons we made. Additionally, staying within the family of mobile devices to develop the user interface kept our goals of mobility and low costs in sight. It also gave us a chance to take into account more design goals of assistive technology on the mobile platform.

DESIGN OF THE WEARBLE AAC BUTTON

No formative interviews were conducted in order to shape the design of the device; it was determined the time to complete the project was too sparse to involve potential users. However, there were informal conversations conducted with parents of possible candidates who were interested in seeing the device developed. Instead, we researched design principles and other design tips already recorded for creating a tool for people with Autism or other disabilities. This section first outlines these principles, and then explains their realizations along with the achievement of its chief functionality in the end product.

Design Principles

Before the development of the project, we researched design guidelines for people with non-verbal related disabilities and outlined the chief principles of our button design.

Small size, lightweight, attachable. The button needs to be small and lightweight so it can be placed anywhere the user wants it on their body. This freedom will allow us to study where people tend to place their buttons, and in what environments do they need to change their previously chosen location.

Ability to connect to the internet. In one of the informal conversations with a parent, they asked us to enable Bluetooth for the device. This influenced our decision to have the button work by connecting to the internet whenever pressed, and ties into our implementation of the next

principle. Additionally, being able to connect to the internet opens the gateway to Internet of Things applications, which is another new field that shows a lot of promise.

Portability of user interface. The device's user interface was created as a mobile application using Xamarin Forms (a cross-platform IDE for programming mobile applications for Android, iPhone, and Windows smart phones in C#). The main idea behind it is if you can program the button's functionality on your phone instead of on your computer, you can take it many more places. Additionally, it has been observed that a large obstacle in assistive technology adoption is the bulkiness or unwieldiness of the devices. This can be seen in the case of Kate and her son Nick in the research paper "Desperately seeking simplicity: how young adults with cognitive disabilities and their families adopt assistive technologies" by Melissa Dawe, when Kate comments on the device she purchased for her son that was unsuccessfully incorporated [4]. Although the LightWriter was the most portable and had the most functions of the devices they were shown, Kate told the interviewer "I kept saying, there has to be something more portable, there has to be something more portable. And I wasn't shown anything. From all the catalogs that they had…"Another mother, Vivian, explained why her daughter Laura never moved her communication device from the kitchen table, and how this ultimately contributed to abandonment: "It was cumbersome, that's a cumbersome thing to haul around for a kid, and then the motivation has to be there."

Simplicity of user interface layout. Along the same lines as portability, the simplicity of the user interface and its layout was essential, because any successful tool has to be easy to learn how to use and program for parents, kids and teachers, or all who are involved in the adoption process [4]. As much as 35% of purchased assistive technology devices are not adopted successfully, which makes it that more important to make the use of the tool as easy as possible while still providing useful functionality.

Low cost and physical attractiveness. Cost effectiveness is an important part of any project, because low production costs means it is easier to distribute and spend time on. For this project, the goal of keeping the cost low determined which microcontroller we bought, decisions we made about the phone being the microphone for the buttons versus each button having a microphone, and other more minor design concerns. For assistive devices, it is important for them to be inexpensive because the user might already be receiving costly care and attention, and if it is easy to upgrade or replace the more likely it is to continue to be used [4]. In one case in Dawe's study, it took too long for Medicaid to pay for the tool and it didn't have enough time to integrate into the user's high school routine by the time he graduated. "Design Meets Disability" by Graham Pullin studies the intersection of design and disability, and sparks conversations on the reasons why "Eyeglasses have been transformed from medical necessity to fashion accessory [13]." The book also acknowledges the weaknesses of current assistive technology design, including the stigma that can attach itself to the user of an unsightly device. To take this into account, we created multiple button covers, the first of which was completed using a 3D printer,

which then provided a surface for stickers or other decoration of the device. Figure 2 shows the cover we made.
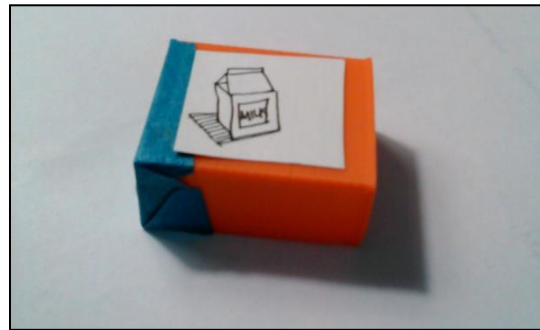

Figure 2. The 3D printed button cover with a piece of tape holding the open end closed, and a sticker paper label with a picture of a milk carton on it. The case was made on a LulzBot TAZ 4 3D printer.

Description of Button

The physical button device we made is composed of a lithium polymer battery attached to the bottom of an Adafruit ESP8266 Huzzah breakout board with a battery connector and button attached. Only the pins for programming it have been soldered onto the board. It is programmed with the FTDI cable with 5V VCC-3.3V I/O from Sparkfun. Beforehand, we also programmed with the Sparkfun ESP8266 Thing breakout board and the original ESP8266 module, but determined the Adafruit board suited our purposes best. The code was written in Arduino and derived from examples from the board's code library. The code itself and other project files can be found on GitHub [6]. When a button is on and connected to the internet, it creates an entry in the PHP webpage's database denoting the unique Mac address of the button's board and the timestamp of the entry creation.

Description of PHP Webpage

The PHP webpage uses a SQLite database to store all the data sent by the buttons being pressed. The code can be found at the bottom of the "Wearable AAC Project CODE NOTES" document on GitHub. The web page it lives on can currently be found at "http://www.cs.colorado.edu/~shaunkane/buttons/buttons.php." Button press data is stored in the database via the add command, which is executed by visiting the url above combined with the addition of this string: "?action=add&id=" with the last part of the address being the Mac address of the button that was pressed (for example: "http://www.cs.......?action=add&id=5546a634fe18" is a valid command). The database entries can be viewed with the read command, executed by visiting the url above combined with the addition of this string: "?action=read." The database entries displayed on that page will be in a JSON format and look something like this:

[{"rowid":"21","buttonID":"5546a634fe18","unixTime":"1437736295","datetime":"2015-07-24 11:11:35"}, …,
  {"rowid":"1","buttonID":"5546a634fe18","unixTime":"1437736235","datetime":"2015-07-24 11:10:35"}]

While listening for button presses, the phone application visits this page to grab information about what button is being pressed at what time so it knows when to play an audio recording or a text to speech segment. Lastly, the addition of the "?action=clear" is the clear command, and the mobile application uses this command to clear the database's contents for housecleaning purposes.
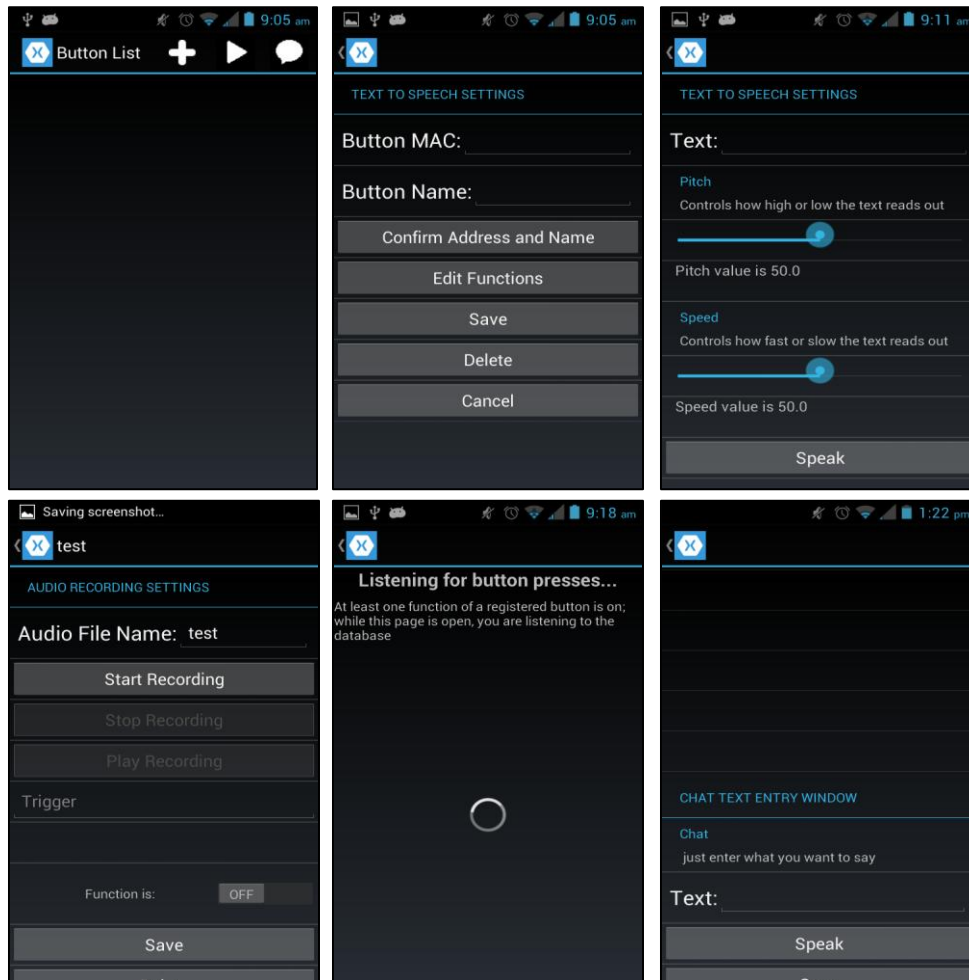

Figure 3. Major menu pages of the Android phone application. From left to right: (1) front page, (2) adding button page, (3) add a text to speech function, (4) add an audio recording, (5) listen for button presses page, and (6) the chat page.

Description of Phone Application

As mentioned before, the project was coded with Xamarin Forms in Microsoft Visual Studio 2012. This code is also available on GitHub. The major menu pages are displayed in Figure 3.The forms can generate an application that can supposedly run on Android, iPhone, and Windows phones, but only the Android version was able to be confirmed to work because of the time and resource limitations. The phone application's chief functions are: button function

programming, listening for button presses and playing the programmed recording when the correct trigger is entered, and a chat feature which allows quick text to speech conversion.

Button function programming is initialized by selecting the plus icon on the first menu. You then enter your button's Mac address and name you designate, such as "Greetings Button" when it is used for storing greetings for people. Next you must confirm the address and name, and to do this the application will ask you to press the button while a popup is open. It will only confirm if both the phone and button are connected to the internet. The phone is visiting the webpage and checking for an entry that occurred after the popup was first open and that has the user-indicated Mac address. Once that is done, you can edit the button's functions by pressing the "edit functions" button on the menu.

To add a new function for the button to perform, you press the plus icon in this sub menu and indicate whether or not you want to create a function using text to speech or using an audio recording. For a text to speech function, it will ask you to enter the text to be converted to speech, and then you can manipulate the speech segment's pitch and speed by adjusting the sliders for each. You can hear it played back by pressing the "speak" button in this sub menu. For an audio recording function, it will ask you to start recording your audio, and when you are finished, stop recording. You can hear it played back by pressing the "play audio recording" button in this sub menu. When you are satisfied, you select a trigger from the scroll menu and turn the function on, so it will be listened for. If you don't want it to be listened for now, you keep the switch turned off. Also, the more button presses you use for your trigger, the harder it is to enter successfully on the button. A low number of presses are best for the trigger in the current version of the prototype. Lastly, you save your entry and return to the button's functions menu, observing the function you just created as an entry in the list (with a check mark next to it if it was turned on). Additionally, no two functions on a button can have the same trigger and be turned on. You will not be allowed to save until one of them is turned off.

To have the application listen for button presses, you go to the first page of the application and press the play icon. Figure 4 shows the button in use. While this submenu is open, the application is parsing information gathered from the database every few seconds and seeing if an activated function's trigger has been entered by the user. When it is, the phone uses it s microphone to play the audio recording or text to speech. To use the chat feature, go to the first page of the application and press the speech bubble icon. This menu stores the last 100 chat text entries. You enter text at the bottom part of the menu, and press speak or the save button. The speak button saves the text in the list and plays it out loud while the save button just saves the text in the list. The top part of this submenu is where you can scroll through your past entries, and select them from the list if you want to play or replay them out loud.

Figure 4. A photo of the button and mobile application being used together.

SYSTEM EVALUATION

We conducted a light user testing study with 4 graduate students from the university in order to identify major issues with the prototype, and an interview with an occupational therapist in which we explained the device's current capabilities and asked for their feedback on how useful it would be for some of their patients and if they had any suggestions for improvement, expansion, or other applications. The results are reported in this section.

Participants

For the light user study, we recruited four graduate student volunteers working in the computer science department at the University of Colorado Boulder (1 male, 3 females, none with a non-verbal disability). It should be noted that the first two students were tested together because of time constraints. All students were recruited through email and face-to-face offers to be a participant. Because they were experienced computer science students, it was our hope that they would offer useful, better-than-average critique of the project. All of them were already smart phone users.

The occupational therapist was emailed the request for an interview, which was performed after the user tests. They were known as a previous contact at the lab, and they have current and past experience working with patients that are non-verbal.

Apparatus

The mobile application we developed was used on an Android phone during the user testing experiments. All other icons were moved from the main page of the phone and only the application icon could immediately be seen. The users were also given one or two of the prototyped and charged buttons to work with, as well as a couple small squares of sticker paper, a pen, and one 3D printed button cover. For the interview with the occupational therapist, we brought the button cover, a button, and the phone with the application on it to illustrate the button's functionality.

Procedure

After the experimenter provided a short introduction to the project, the users were asked to perform a series of tasks using the materials provided to them and think out loud while the experimenter took notes. The tasks instructed the user to: (1) pair the button with the application and record a voice message for it and test it, (2) draw a picture representing the given phrase on a piece of sticker paper and attach it to the button, (3) change the first recorded message to a different message and test it out, (4) Add a second button (or in the case of working with a single button, add another function to the same button) that uses text to speech for a third message and create a sticker for it and test it out, and (5) use the chat function to speak another given phrase. Once a task was completed successfully the users would move on to the next task.

The users had to blindly explore the application in order to figure out what they needed to do for each task; the average session took about 30 minutes. If the users were struggling and not getting anywhere, the experimenter provided hints or instructions on what to do next. When users finished all the tasks, they were asked to answer a series of seven follow up questions: (1) overall what did they think of using the prototype, (2) what was confusing about using the prototype, (3) how can we improve it, (4) if you were using the prototype, where would you put the button, (5) how would you want to attach it to your clothes, (6) how could we improve the hardware design of the button, and (7) did they have any other feedback. When the experiment finished, they were thanked and dismissed. For the occupational therapist interview, we presented the project and talked about feedback and suggestions. It was less structured than the user study.

Design and Analysis

The design of this experiment was qualitative instead of quantitative, and thus analysis is focused on categorizing what feedback was repeated or highlighted the most by participants in the user study. Feedback for improvements and further applications was focused on the most from the interview with the occupational therapist.

RESULTS

Qualitative Feedback from User Study Participants

We will first note major issues with the application the users encountered during their task performances, and then provide a summary of their responses to the follow up questions.

Two of the four participants struggled with understanding the functional meanings behind the icon-only buttons on the first page of the application; for example, one mistook the play icon (the listen for audio button) for the recording area for a phrase. It was suggested by these participants to label the submenus with words, or words in addition to icons. The most prominent issue for all participants was trouble with understanding and navigating the menu and design structure. All four made errors or required hints for where they needed to be in the application to perform certain tasks. The two areas of the application that were most prone to error were the confirm button and set trigger tasks. The confirm button function did not work more often than it did, and

the trigger dropdown was consistently overlooked, which some participants said was because it came after the speak or play audio recording buttons which were prominently displayed, and the trigger drop down was displayed in a less distinct color. The use of the keyboard to enter the complicated Mac address was also annoying to most participants. On a positive note, all users found the sliders for pitch and speed enjoyable to test, and the second time they had to perform a task they always performed them quicker. Some enjoyed making the stickers, but could not always find a suitable surface when the button was not in the 3D printed case. Errors in the provided instructions or intuitiveness of the tasks highlighted the vagueness of some of the popup messages and the button name entry.

Overall, what did you think about using this prototype? Most answers varied, but most thought it wasn't intuitive or easy to use in the beginning, but got easier later; two said they had fun using it once getting used to how it worked.

What was confusing about using the prototype? All commented on the unclear icons, the overlooking of the trigger problem, and two thought the function state should automatically be set to on, because the default of it being off was a bit confusing. One suggested that the cancel buttons should be removed because they perform the same task as the back button (which actually needs to be confirmed at this point in time). The same participant mistook the pairing menu for the listening menu. Two wanted more visual cues that the button was on or was performing a task. The participants also wanted more succinct popup messages, and a greater number of them in some situations. The menu structure was also confusing for them, and one suggested putting the chat function at a different menu level because it is not involved in the button programming and listening functionality.

How can we improve the prototype? All participants suggested the adding of additional voice options so users could at minimum gender themselves. Two suggested creating a tutorial for first timers, and the inclusion of preset phrases on new buttons to help people teach themselves and be able to immediately start using the application. All wanted the "edit button functions" button to be moved from its submenu and instead be placed right next to or inside the button's listing on the first page, as sketched in figure 5 below. A labeling system was suggested in order to assist future users with organizing their buttons. Lastly, all suggested that the button be made smaller and lighter weight.

Figure 5. The improved list item format proposed by the users.

If you were using this prototype, where would you stick the button? The most popular responses for this question were for users to indicate that they would wear it on a belt, wear it as jewelry or other accessory, wear it on a bag, and wear it somewhere on their arm. Other responses were to wear them in shirt pockets, on a backpack, as a broach, or on a forearm or upper arm.

How would you want to attach it to your clothes? The first two participants said they would attach it with a clip "like the iPod shuffle," or use snaps or Velcro. They also suggested sewing the buttons into accessories such as bags. The other two participants suggested using clips or pins, and one said if they were small enough they might use them as actual clothes buttons.

How could we improve the hardware design of the buttons? All participants suggested making the button smaller and lighter weight. As mentioned before, two wanted more visual cues of the button performing tasks. One suggested sawing off the programming pins after the code was loaded onto the board, because the pins contributed to some of the bulkiness of the current prototype. Also it was suggested that the button be made easier to charge.

Do you have any other feedback? One participant shared the idea of using machine learning to generate phrase suggestions as an easier way for the user to avoid having to type as much which takes more effort and concentration than most user inputs. Another suggested using a Mechanical Turk repository of phrases. The third commented that the application seemed to currently not have a larger benefit than just texting does, and suggested in the future to target a more specific user group and focus on making it more meaningful to them. They gave the example of using the buttons to communicate essential phrases in a different language for travelers in foreign countries. The last tested user commented that depending on the situation she was in, she would place the button in different places.

Qualitative Feedback from Occupational Therapist

The feedback from the occupational therapist can be broken into four major categories: additional background information on the target audience, suggestions on how to improve the design, ideas for further applications, and interest in further involvement.

Additional background information. When we asked more about the therapist's non-verbal clients, she first talked about their range of verbal ability. Her clients had a wide variety of capabilities, including some who were semi-verbal and some who could speak but not very clearly. She offered the example of a condition called speech apraxia, which is a speech planning issue that can cause repetition and struggle, and is present in about 50 percent of cases of autism. She also expounded upon the high abandonment rate of assistive technology, and commented that she had never seen one of her clients switch to solely using an assistive device. With autistic individuals, she practices things like eye contact and noted that someone else might need to program the buttons for an individual, because some of her clients who have trouble speaking also have fine motor impairment or can't type.

Suggestions for improvement. Firstly, she mentioned the logical grouping or organization of the phrases should be simpler, such as categories of what the client wants and doesn't want, or a simple yes or no, or a button for emergency information such as their name, phone number and

address. She agreed that the device should be smaller, and suggested that the physical design be targeted at a specific age group. Other suggestions included color coding the buttons, maybe adding a display screen, putting it on a belt or a headband, and adding more voice options so they could gender themselves. She also suggested making a tutorial for it so it is easier for therapists and teachers to learn how to use. To reduce complication, she also suggested being able to record on the button itself so it has value outside of the phone or an environment with internet.

Further applications. One future application of the device she came up with was using the device to assist individuals when they are out in the community, like when they are working a job or taking the bus. She suggested using it as a digital read out for the blind deaf, or could be used for practicing beginning language learning or choice making. Lastly, she suggested offering it to developmentally disabled individuals and people with Alzheimer's in order to use it for remembering things.

Willingness for further involvement. Overall she was interested in where the project could go, and commented that her and her clients could be a part of a future workshop or study. Additionally, she also recommended another source of study participants to be from the Imagine Center for Boulder County.

DISCUSSION

We conducted four light user experience tests and one interview with an occupational therapist in order to evaluate the phone application and button device for its usability and future potential. We also had a goal of determining where the placement of the button would be on a person's body. During the user study, all participants needed assistance navigating at one point in the task executions, which indicate that the application needs more work - specifically in the areas of menu structure and format, instruction clarity, visual cues, and intuitiveness. All participants also recommended that the button be made smaller and light weight, presumably so it would be easier to place or wear in a wider variety of places (one participant suggested wearing it as an earring, but the current device was too big and heavy).

When asked about the placement of the button, the participants notably did not indicate a willingness to wear it anywhere on their legs, and attaching it to accessories was a popular answer as well. When asked about how they would attach the button, they specified that an accessory could have the button embedded in a permanent manner (such as on a bracelet, necklace or belt), but otherwise they would chiefly want to attach it with clips, then pins, Velcro or snaps. Most participants and the therapist were excited about the potential of the project. But although the device shows promise, it certainly needs more work. A few major design implications gathered from the study are outlined below.

Making the device meaningful to a specific audience. As one user mentioned, in order to create a good tool we need to gain a deeper understanding of our target audience's needs and abilities. Our interview with the occupational therapist lent us more insight into the needs of a

non-verbal audience, and offered up contexts of use and ways in which they might struggle with it. In the future, it is suggested that the device be tested and further developed with its potential users.

Making the device meaningful in the context of existing tools. When a user compared the application to text messaging, it was clear that the device was not perceived as anything new. Additionally, before development we did not have a chance to make many comparisons between our device and existing AAC devices. It is important that the button be compared to existing work so it can improve upon it instead of duplicate it. The ability to connect to the internet should be taken advantage of, and used to explore its Internet of Things potential.

Small size and weight affects button placement. In order to better study where people would place wearable devices on themselves, the device needs to be perceived as being able to be placed anywhere. When participants answered the question of where they would place the button, it was observed that they relied on comparisons to existing things people wear such as jewelry or small music players which were the same relative size, shape or weight as our button. In the future it is suggested that the device be made even smaller and lighter, in order for users to place it in more areas on the body. Another important reason to include target users is because some have multiple disabilities, and would likely require the button to be worn in a wider variety of places.

Further simplification, clarity and organization of the user interface. Further simplification and streamlining of the design is desirable for our application in order for it to be more useable, have better functionality, reduce its rejection potential, and to offer more function and utility.

CONCLUSION

Our results show that there is some potential for this device to be useful for non-verbal individuals. All participants were excited about the application, most notably the occupational therapist, who knows our user group the best. It also seems to be one of the smaller AAC devices, as most described in the background research were bulky, table-bound objects that tended to be expensive (usually costing a few hundred dollars). Comparatively, one of our buttons only costs about $15 dollars to make, and is easily assembled and programmed. Once work on improving the hardware design and user interface is performed among other concerns, further testing is recommended.

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