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EVALUATION OF HAPTIC AND AUDIO FEEDBACK NAVIGATION FOR PEOPLE WITH VISUAL IMPAIRMENTS

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by Ramsha Rao

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ABSTRACT

Assistive technologies are becoming prevalent among people with visual impairment (PVIs); by definition such supports can increase these individuals' autonomy in their daily lives. Examples include Artificial Intelligence powered applications, applications using Remote Sighted Assistants, Braille Technology, Screen Magnifiers and Readers among many others. Among these technologies, Remote Sighted Assistant applications are garnering considerable attention; these use the novel paradigm of a conversational agent who guides the PVIs through a video-mediated conversation. My thesis project investigated novel augmentations for a Remote Sighted Assistance service called AIRA. The specific goal was to support PVIs in navigation within the task context of grocery shopping (moving around a store but also acquiring target products). Working with a larger team, I investigated a wristband that provides haptic (vibration) feedback (with the help of the four attached vibration motors that are controlled by an Android application) to the participant for obstacle warning and hand navigation. The haptic information is combined with audio (spoken) feedback from the Remote Sighted Assistant who communicates through a video call; this enables the agent to see what is in front or around the participant and provide corresponding guidance. The prototype was tested on sighted, blindfolded participants to examine its strengths and weaknesses, and to gather suggestions for future device improvements. The valuable feedback received from the participants will be helpful for both our own future work and that of other researchers working on these kinds of system

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Chapter 1

Introduction

In 2018, WHO (World Health Organization) ("Vision impairment and blindness", 2018) reported that around 1.3 billion people have some sort of visual impairment; as these numbers increase, so does the need for assistive technology to help them in their daily lives. As most of the people are aware, PVIs usually go about their work using a cane or guide dogs. Over the last couple of years assistive technology have also been making waves amongst them.

It is no surprise that our sight plays the main part in our daily activities, especially in navigation and understanding direction that is essential in our day to day lives. And PVIs have to rely on many different aids such as dogs or canes to help them in this task. This becomes worse when PVIs have to visit unfamiliar places, or if there is an obstacle on the road such as pothole or branch of a tree or a rush hour traffic as they have to use their other senses as well to interpret any danger ahead (Giudice et al., 2008) as these aids do not always work perfectly.

Furthermore, humans can be used as aids as well but PVIs don't want to burden their family members or friends all the time with their daily tasks and like to be independent. PVIs value their independence and don't prefer relying on other or asking for help all the time. And sometimes it is possible that someone is not present to help them (Bigham et al., 2011).

These issues are why assistive technologies are becoming really popular such as applications using applications using AI, Remote Sighted Assistance (RSA) and haptic feedback. We focused on RSA due it garnering fame in the recent years as it gives the PVIs the independence to do what they want to do without relying on anyone else. It includes a remoted, sighted assistant or agent that describes the visual data via speech or text. RSAs can provide help in many different ways, such as locating objects in their house, reading, navigation, social interaction (Lee et al., 2018) etc. However, the issue with them is that these agents can only describe so much to the participants (Lee et al., 2018) in a limited amount of time and due to which RSAs experience difficulty in that department. This prompted us to find improvements in the current RSA systems to make better and improved prosthetics and led us to combine haptic feedback as haptic cues are proven to be faster than the conversational ones.

In this paper, we discuss the usability study of the prototype that uses remote sighted assistant or agent (RSA) paired with haptic feedback. Haptic feedback was added as sometimes just conversation is not direct or prompt mode of communication whereas haptic or vibration can achieve that. Our study is also an example of derived form of Wizard of Oz where the participant knows that another human is used as an RSA. And on the other hand, as the navigation system is not fully developed and is still in a prototype phase, so team of people are needed for assistance.

The main crux of the paper is to test the system on sighted, blindfolded participants while grocery shopping as there is a lot of unpredictability in super markets and many events can pose threat if not properly taken care of, and then getting their feedback in understanding if adding haptic cues to the existing RSA make it a better design and the prototype is actually helpful and clear in conveying the information to the participants.

The paper is organized in the following way: the next section will talk about related works using the organization of prosthetics, AI assistive technologies, Remote Sighted Assistance and haptic feedback devices and issues with them. The following sections will focus on the description of the device and the background work and their results. After that, the section on the testing the prototype on the participants and their evaluation. In the end, discussion and future work to discuss the improvements and suggestions to make the prototype better for the PVIs.

Chapter 2

Related Works

In this section, I will be discussing the state-of-the-art devices or application made for PVIs and the issues with them.

Prosthetics for PVIs

With so many people suffering from visual losses that many scientists and researchers have come with prosthetics to help better the condition, called as visual or retinal prosthetics. But these prosthetics have not been fully achieved as there a lot of issues that need to be taken care of such as fully understanding the anatomy of the eye and conducting first on animals to make sure their safety. And the prosthetics that have passed these stages are still in their initial phases of testing on humans and cannot be released yet (Weiland et al., 2004). But whenever the prosthetics hit the market, they can be really helpful in helping the PVIs lead an independent and safe life, but they might have a downside of being expensive and not everyone been able to afford them.

Applications using Artificial Intelligence

There are many applications that have been using AI or computer vision to help the PVIs. One such example is an article published in a tech publication, TechCrunch, regarding Seeing AI; application from Microsoft that converts visual feed in to speech (Coldewey, 2019) such as texts, colors, recognizing emotions and also describing the objects in the picture etc. But it cannot not be used for navigation which is one of the main tasks in every-day life. Moreover, there are many people who cannot access it due to financial reasons as the application is only available for Apple iOS and most PVIs are not economically strong to afford an iPhone (Reese, 2017) as published in another tech publication, TechRepublic. Also, it cannot completely interpret peoples' emotion correctly (Bell, 2017) that would be crucial in a social setting.

Another device that uses AI is OrCam. That includes eyeglasses paired with a camera that helps blind person to understand social cues and read text (Pauls, 2018). But there are also some limitations with this such as not correctly recognizing gender of a person, short battery life and steep price that would discourage many people from buying the product (Pauls, 2018).

Remote Sighted Assistance

RSA has been in use a lot lately. AIRA is such an example of such system. It is a subscription based service that uses smart glasses with camera and speaker, connected to a smartphone, to help PVIs (Kelley, n.d.). It is basically a user calls an agent through AIRA application and an agent helps in navigating by describing the surrounding to the user and it all happens in real-time. It also helps in their other daily tasks such as reading a book, taking pictures, washing clothes, in classroom etc (Lee et al., 2018). PVIs find it very useful as discussed earlier however there is only so much information that the agents can convey to the PVIs at a time. Moreover, as it is a subscription based service, people coming from low-income families cannot afford it, even though PVIs and people with disabilities are at a greater risk of having unemployment and financial problems as compared to other people.

Another example of RSA application is TapTapSee. This application relies on crowd sourcing to help the PVIs in object recognition in the visual data (Kelley, n.d.). TapTapSee uses both Artificial Intelligence and humans to recognize objects. For the human part, user takes a picture or records a video and the application forwards it to the sighted volunteer and they send the description back to the user within seconds as published by Kelley, who is the Certified Assistive Technology Specialist for PVIs, in a blogpost. One of the limitations of this application is that it is not in real time and can take some time to get the results back. This might not be ideal in a fast-paced environment. Be My Eyes is another example of crowd sourced application where a PVI calls an "untrained volunteer" (Avila et al., 2016) and connects with them via a video call. According to a survey conducted by Avila et al., the users found the application useful in certain situations such as reading, locating objects, shopping etc but not in the case when the hands were busy. Also, some users also were reluctant in their sharing their privacy information with the strangers as they were just volunteers and not trained officials. Moreover, some users suggested to provide training to the volunteers to improve their conversational skills.

Haptic Feedback

Over the past years, there have been a trend of coming up with devices that can provide haptic the PVIs while navigating. PVIs have found haptics really helpful in in the case of missing audio feedback. In a study done by Jay et al., haptic cues really helped the participants in recognizing the different objects (Jay et al., 2008). Haptic feedback has also been used in wayfinding where users liked the idea of using vibrations on a smartphone and found it to be effective (Azenkot et al., 2011).

Another experiment done by McDaniel et al. found out that the haptic belt proved to be effective in conveying information regarding distance and direction of everyone (in the visual field) with respect to the user (McDaniel et al., 2008). Additionally, smart cane, another example of haptic and audio feedback, warns PVIs of obstacles with more accuracy of a normal cane and in turn reduces their chances of mishaps. The cane uses speakers or vibration gloves for people who can't hear in helping navigate them. But there are some setbacks to this design as it also works for a small area, similar to a simple cane, can be expensive with the installations on the cane and takes space (Helmy Abd Wahab et al., 2011).

Chapter 3

Prototype Design

We examined the use of haptic or vibration cues in tandem with the conversational feedback from the agent after researching at the current issues and studies and came up with the prototype.

Initially, we designed a glove-based device with vibration motors attached to the fingers for haptic cues. But it was bulky and limited the movement of the hands of the users. So, we wanted to come up with a design did not hindered the users' movements, was comfortable and did not tire the users after using it. Our team researched to find devices that would provide these features and found Ditto that are light-weight clip-on devices connected to smart phone via Bluetooth and vibrate when given a command. They have different vibration patterns such as vibrating once, twice or customized vibrations for different applications etc. Basically, it was designed for people with hearing loss so they could be notified of calls or messages and still be hands-free in certain situations such as if the phone is in a bag, during swimming etc. ("Wearable Device Frees", 2016).

Ditto was light- weight and comfortable to wear so we decided to test it for our prototype as well. We tried different placements for the device, using the wristband that it came with, and patterns to make sense of what felt natural regarding directions and obstacle warnings. After trying and testing different combinations, we chose the wrist as the most suitable place for the device.

However, we could not continue using Ditto as 1) there was a technical issue with the device that the vibration patterns were not consistent, so for instance when we gave the command for two vibrations, it would sometimes just vibrate once and due to that the participant was not always getting the right information. And 2) due to the nature of the Ditto device being a single point of vibration on the wrist, the team had to come up with different patterns to correspond four directions and they did not feel natural to the to the directional mapping. Finally, 3), the vibration strength of the Ditto device was not really great either the motors were inside the plastic casing that was in contact with the skin.

Keeping these issues in mind, we designed our prototype, Haptic Wristband (HW). The team came up with a simple Velcro wristband with four vibration motors, corresponding to the four directions (top, bottom, left, right). These motors seemed more natural to the directional mapping as there were four different points of vibration sources around the wrist. The exposed motors also meant to increase the strength of the vibrations felt by the participant, that the Ditto could not provide.

However, the motors on to the band proved to be a problem as fixing the motors meant it could not accommodate different wrist sizes, which could lead to different experiences. So, after that, we attached small Velcro strips to the four motors so they could be moved around easily to cater to different wrist sizes and also adjust the directions easily.

Chapter 4

Haptic Wristband Features and Implementation

For the Haptic Wristband, user wears a wristband with vibration motors that are controlled by the RSA with the smart phone application. The device was made in manner of the wristband so that it would provide free and easy movement in navigating that hand. RSAs help the users mainly through conversation as they describe the surrounding of the users as agent sees everything on their screen through the participants smart phone camera with the help of video call (they both are connected through a call) but also provides haptic feedback for obstacle and to navigate the hand. The conversation paired with the vibration gives the users different information regarding their surrounding and any obstacle ahead of them at the same time so the user can be well informed at all times and also, it avoids to describe the obstacle again and again by just providing haptic feedback.

Hardware

The device consists of a simple Velcro band with four motors attached to it that corresponded to left, right, front and back which were used to output the haptic feedback and also to signal the user to move themselves or their hand in the corresponding direction.

The appearance of the band can be seen in the Figure 1.

Figure 1: Haptic Wristband Prototype

Software

The four motors corresponded to the similar buttons on the application screen. And for the video call, Google Hangout was used. Moreover, the vibration pattern used for navigating around the grocery store is given in Table 1:

Pattern	Meaning
Once on the right side	Obstacle on the right
Once on the left side	Obstacle on the right
Once on the top side	Obstacle in front

Table 1: Vibration Pattern for Body Navigation

Furthermore, there was another set of pattern that was used to navigate the hand once the user reached the shelf, stated in Table 2.

Pattern	Meaning
Once in any direction	Move the hand in the corresponding direction
Twice on the top side	Reach out and grab the item

Table 2: Vibration Pattern for Hand Navigation

The application screen with all the four buttons is shown in Figure 2. The “FRONT” button is used to vibrate the top motor, “RIGHT” button for the right motors, “BOTTOM” button for the bottom motor and the “LEFT” button for the left motor. The number of vibrations by every motor depend on the number of times the corresponding button is pressed, e.g. pressing the “FRONT” button once will make the top motor vibrate one time, pressing the “BOTTOM” button twice will make the bottom motor vibrate two times and so on. The light blue area with “Bluetooth Connection” is used to connect with the Bluetooth of the Haptic Wristband.

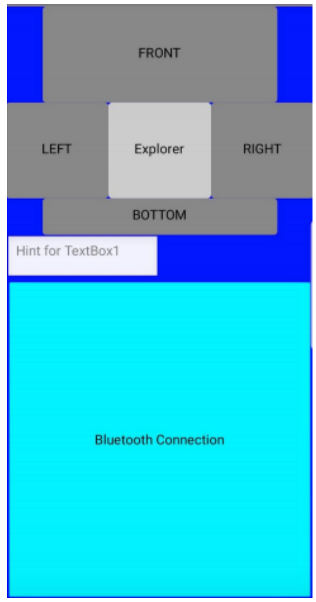

Figure 2: Smartphone Application Control Screen (Android Version)

Chapter 5

Field Trial of the Haptic Wristband

The goal of this study was to test and examine the Haptic Wristband, procedure and recognize any issues with the prototype or/and the study and improve it to test it on PVIs. These two procedures were chosen so the participants could compare the conversation only feedback with conversation and haptic feedback, and give us insights in to what procedure was more helpful and practical.

Study Site

We conducted the study on to two blindfolded participants at Wegmans (super market). This is a big supermarket with a basic layout of aisles on the right side and the other departments (produce, home goods) on the left side. We conducted our study on the right side where the aisles were situated because they were easier to navigate. We asked for permission from the management at Wegmans before-hand to conduct our study and for permission, one of the researchers emailed the managers before the study. The main condition from the management at Wegmans was to conduct the study after 8 pm. It was because before that time, there might a lot of customers and our study would cause interruption to them, so we conducted all out studies at or after 8pm.

Participants

Both the participants were male and sighted. These participants were chosen by simply asking them as they were friends of the research team. We used the sighted participants as it was convenient to simulate the situation by blindfolding the participants and asking them to test the prototype described in the previous sections. And also, we could not test the prototype on the PVIs due to them being scarce and the project still in prototype phase. Both the participants had experience with haptic feedback in terms of smartwatches and gaming where the player receives haptic feedback in some situations.

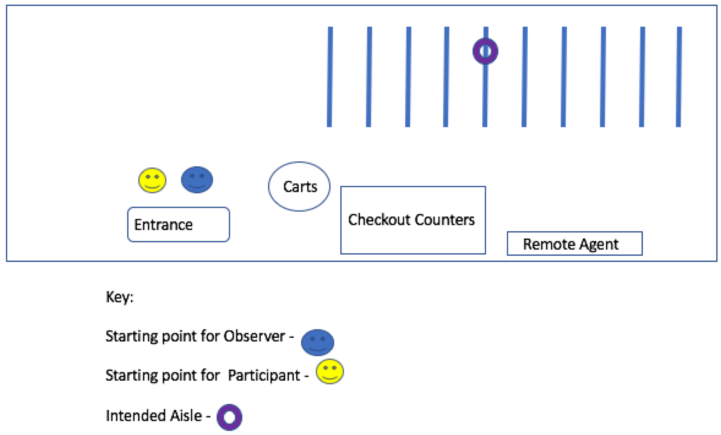

Figure 3: Layout for Participant 1

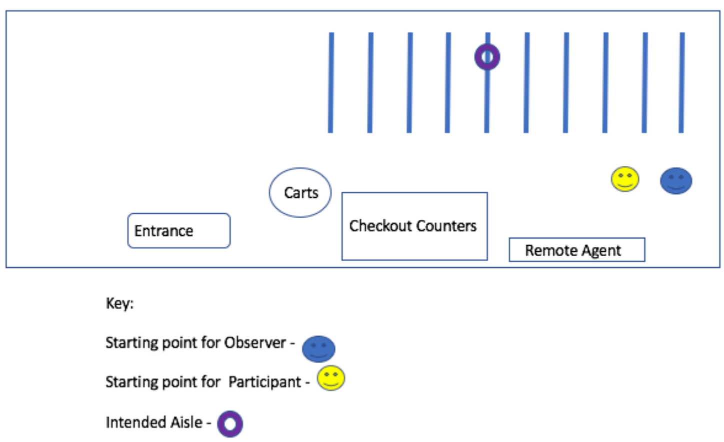

Figure 4: Layout for Participant 2

The pictures above show the location of the starting points of the observer and participants for each participant and the location of the remote agent and also the location of the intended aisle where the object to be acquired is places. The testing settings of both participants were different. The first participant performed the first procedure two months before performing the second procedure that included the haptic feedback. This is because the prototype was not ready when we tested the first procedure and has to wait a couple of months. For the second participant, we tested both procedures on the same day as the we had the functional prototype at that time.

Both participants had different routes for navigation from each other, but the each followed the same route for each study. Participant 1 started their navigation from the start of the Wegmans whereas participant 2 started from the back of Wegmans, due to the fact that there were a lot of customers at the entrance and we were instructed from the management not to cause interruption to them.

Task Procedures

We tested two procedures on each participant. First one was RSA guiding the participant with just the conversational feedback for direction, obstacle warnings and hand navigation. And the second one was Remote Sighted Assistant guiding the participant with the conversational feedback for direction and haptic feedback for obstacle warning and hand navigation. Both procedures for both the participants were video recorded and then their responses were audio recorded as well. Before conducting the second procedure that included haptic feedback we described the prototype to the participant, trained them on what each vibration meant and how to interpret them in the case of body navigation and hand navigation. Then we tied the prototype around the participants' wrist, tested it and made sure the participants knew how to interpret different feedback. For both procedures, Remote Sighted Assistant found a quiet place from where they could give assistance to the participants.

The task was to guide each participant around Wegmans to get to the correct aisle and once they were in front of the correct shelf, help them in getting a particular item. Remote Sighted Assistants or agents, before starting the study, familiarized themselves with the aisle and the correct shelf so they could correctly guide the participants without any confusion. These agents were trained and assisted other agents in preliminary studies to get acquainted with the process. The agents and participants were connected though Google hangouts or Google Duo, and the participants smartphone camera was used by the agent to see the surroundings. The participants were also given a blindfold to cover their eyes and a cane to mimic the PVIs and also to perceive the obstacles in front them better. The agents described the surroundings to the participants in addition to the feedback as well to make the interaction seem like a conversation and also to give them the idea of what is in their surrounding except for any obstacles. Additional observers/researchers were also present with the participants to make sure they don't hurt themselves and also to take videos and notes.

Data Collection

After the studies were done, we interviewed by asking the questions provided in Appendix A, regarding their whole experience and audio recorded their interviews. The time took by each participant for training, navigating from the start to standing in front of the correct shelf and hand navigation were measured with the help of the video recordings. First participant can be seen in below in Figure 4 and the second participant in Figure 5.

Figure 5: Participant 1

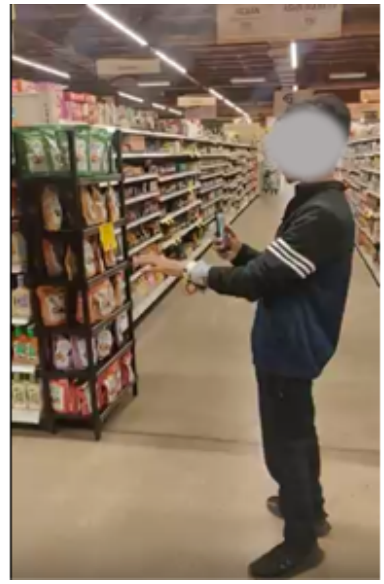

Figure 6: Participant 2

Chapter 6

Findings

Overview

First participant had a higher total time as compared to the second one, mainly because first participant's route was longer as compared to that of the second one as discussed previously and also second participant walked considerably faster than the first one. First participant spent around 2 minutes on the training to understand the prototype whereas the second participant spent around 4 minutes. This is due to the fact that the participant one was confused about the top and bottom motors of the band and took some time to adjust and differentiate different vibrations.

This study gave us some useful findings that would prove to be helpful for our main study with the PVIs.

Audio Feedback Only

Both the participants navigated to the correct aisle without any issues for the first procedure. But for the hand navigation to the correct product, the participants faced some problems. The participant had a cane in their hand when they were reaching for the shelf and the Remote Sighted Agent had to ask them to give it to an observer so the participant could grab the box. Moreover, the second participant also faced the problem with cane getting in the way when they picking the product from the shelf but before the observer could take it away, the participant accidently dropped it on the floor. This study highlighted some issues in design and implementation of the prototype. First of all, the cane that was a part of our design interfered with the participants hand movements during picking out the object. Cane is one of the most important aids that the PVIs use and we have to design our prototype by factoring that in as well.

Secondly, we observed that during hand navigation, both the participants had to be asked to adjust the camera and align it with the other hand as the participants forgot to do that and concentrated more on the other navigating hand.

Combined Audio and Haptic feedback

Before the start of the study the, the participants were given training to equip them for the navigation. Both participants experienced difficulty in feeling the vibrations on their wrist at certain times which could be due to the wrist band not touching the wrist at all times, especially die to the pocket formed on the bottom side of the wrist, strength of the vibrations not strong enough and the wires interfering with the rotation of the motors. The vibration motors were not always touching all the sides of the wrist that led to participant not feeling the vibrations at some point and also decreased strength of the vibrations. We designed for the participant for to feel the strong vibrations at all times but after testing it, we encountered these issues that need to be addressed in the future work.

The second participant was initially confused between the top and bottom vibrations during the training phase as they told us that both vibrations felt the same. Due to that we had to spend some extra time in order to make the participant differentiate and interpret the vibrations clearly.

Moreover, the first participant used the cane in this procedure as well whereas the second participant did not use as they did not feel it provided extra level of safety. As the second participant did not have a cane, they put out their arm (one with the prototype on) in front of them while walking as seen in Figure 5.

Furthermore, when the first participant was carrying out this procedure, the Bluetooth disconnected after a certain distance and due to that the procedure had to be stopped for a short amount of time to connect the Bluetooth of the prototype with the smart phone application. To avoid further disconnections, the Remote Sighted assistant had to come near the participant and give directions from there. Whereas, this did not happen for the second participant as the agent and the participant were always in range and the route was shorter as compared to the first participant.

Also, the second participant lightly hit their left foot on the shelf during walking in the aisle. Additionally, during this procedure both the participants again had to be adjust the camera while navigating their hand so the agents can get the proper view of was in front the participants. In addition to the participant two was not satisfied with the idea of holding the smartphone for camera as it would interfere with the participants' abilities to carry or move the cart.

Interviews

The results from the interviews were mixed. When asked if the haptic and conversation feedback was better and helpful than just the verbal cues, first participant replied that they liked the idea of adding haptics to the audio feedback and felt two information channels were better than just one. They felt that the haptic cues were more "direct and fast" than the audio cues. In answer to the question if the haptic cues were helpful for obstacle warning, first participant replied haptic feedback helped the participant to understand the situation better by introducing vibration and conveyed the information quicker as compared to audio that can introduce some lag in trying to warn about the obstacles in the way. In the case of the hand guidance, first participant felt that the haptic cues were quicker than the verbal cues. However, first participant felt that the agent can be trained better in giving the verbal cues so it would lead a better communication between the participant and the agent

However, second participant did not share the same views as the first one. The second participant felt the verbal cues conveyed more information and clear as compared to haptic and verbal cues combined in that setting. We asked the participant why they felt that way, they replied that the haptic cues felt confusing. Additionally, the second participant answered the haptic and audio combined were overloading their cognitive abilities as they had to pay attention to two feedback channels at the same time, when asked if the feedback overloaded their senses at some point. When asked if the verbal cues were clear, the second participant replied that they fully understood them and were more than enough for the navigation. When prompted if the second participant felt the prototype could be useful in a crowded area where there is a lot of information has to be conveyed, they agreed that the vibration can be used as a secondary mode of feedback, in addition to the verbal cues.

Moreover, participant two elaborated more on the haptic cues by telling us that they did not feel intuitive and did not map naturally to the four directions as the wristband was on just hand so it was difficult to navigate the whole body from the reference of just one hand. Participant two came up with these comments on their own, without being prompted. These comments by the second participant made us realize the need for a more intuitive system and providing enough training to the participants.

Furthermore, both participants did not have any concerns with the wristband prototype itself, of it being too heavy or uncomfortable and said the band itself was comfortable.

Discussion

This study shows us that the vibration can be helpful in cases there is a lot of information to be conveyed as discussed in the paper by Lee (Lee et al., 2018) and can be used as a secondary form of feedback. In the study done by Azenkot et al. they also found out that vibrations are helpful in wayfinding and out study also confirms that. But there is a need for more better design of the prototype that can deal with the issues mentioned above.

Moreover, as this prototype used video call and participants don’t have to wait to get the results back as it happens all in real time, something that TapTapSee (Kelley, n.d.) lacks. Also, our design uses trained agents who can be trusted and know how to communicate with the participants, something that lacks in some applications (Avila et al., 2016). Furthermore, AI has been used to identify peoples’ moods in different settings but it is not always correct (Bell, 2017), but the video aspect of the prototype allows the agent to correctly describe the surroundings to the PVI.

However, there are some issues with the design as well that we encountered while doing some background research. Participants did not like find RSA useful when they had their hands busy as discussed by Avila et al. in their paper and after our study, we also found out the similar result when one of the participants voiced similar concern. We already tried hanging it around neck but it moved a lot. But we can use try using different kinds headgear or smart glasses in the future to determine their feasibility.

Chapter 7

Implications, Limitations and Future Work

The studies received mixed reactions from the participants about the haptic feedback and positive feedback for the wrist band and audio feedback. Based on the data collected, we will discuss implications of the findings.

Firstly, both the participants had to be reminded to adjust the camera while navigating their hand. To fix this issue, it might be better to give more training and conduct more tests to make sure that the participants get the hang of it after a few tries. And if it still poses a problem, it might be better to get a better camera that would allow the Remote Sighted Assistant a better and wider view of the surroundings of the participants so he agents do not have to remind the participants again and again.

Also, as participants had difficulty in differentiating and understanding the different vibrations clearly, the researchers the can provide more training to the participants so they get better after every turn and if that still does not work, the researchers can invest in better motors with adjustable vibration strength but that would make bigger and heavier motors eventually leading to a bulkier prototype. These are some of the implications that can be tested and recorded to better understand the pitfalls and shortcomings of the existing prototype so it can be improved and made better.

There were also some limitations the testing. Firstly, the sample was small and we could not use that to approximate the population and fully estimate the results as both participants had opposite views of the prototype. Secondly, the prototype is still in the initial phase of development and due to that it sometimes it rums in to technical difficulties than can halt the testing such as vibrations not felt by the participants, Bluetooth disconnection or one of the wires of the motors getting loose. Finally, there was a lack of counter balance in the procedures as each participant followed the same route for the first and the second procedure which could introduce “confounding” variables as each participant might already have an idea about what to perform in the second task (haptic + audio) as they had already done the similar thing in the first task (audio only).

For the future work, the device can be restructured in a way that all the motors are in contact with a more sensitive area of the body so the vibrations would be easier to feel such as palm or fingertips. More training, to both the participants to make them fully aware of the system and agents to help them communicate better with the participants, is needed. This would help us if the problems in interpreting the vibration lie with the training or position of the vibration motors.

Also, test the prototype three or four times on the same participants to identify if the participants get better and quicker at navigation after each time. If they do, then that means there exists a learning curve in using and understanding the prototype. Along with this, we can also plan a study for long term and record how the participants feel about the prototype after that time.

Additionally, we can look into Apple watch as well to replace with the prototype due to its ability to provide haptic directional feedback. It already has pre-installed vibration patterns for directions and would be more reliable than Ditto as we would not have to worry about technical issues that much. But there would be learning curve for the participants as well because again, like Ditto, it has a single source of vibration on the wrist.

Furthermore, testing the prototype again with introducing counter balances, may be starting half of the sample group with the audio only cues and other half with the haptic and audio and also giving different routes to the participant for each procedure so the researchers can make better decisions and check if there were any potential confounds. Lastly, as the sample group was small in this case, it might be good idea to test the prototype on a larger group of people that would allow us to better approximate the population and would get rid of any idiosyncrasies in the data so that we can make better and informed decisions.

More significant design changes such as testing with two wristbands for both hands and comparing with just the one, can be done as well. But we have to be mindful and stop at a certain point as we cannot continue making huge changes to the design or else would be stuck in an infinite loop of re-structuring the device. Instead of that, we can provide more training to the participants and fix the issues in the implementation of our device that we did not though of earlier in our design.

Appendix

Interview Questions

1. How would you describe the audio and vibration feedback?
2. How helpful were speech instructions? And vibration instruction?
3. How did you like the guidance and were you able to interpret them easily?
4. Was the feedback given at correct times?
5. How was the experience of the band? Was it comfortable, easy to use?
6. Did the system overload your auditory or cognitive processing?
7. Was the whole prototype simple and easy to use?
8. How was the idea of using phone application to interact with the agent?
9. How helpful was it was? And where do you think it will be useful other than shopping?
10. Would you use it on a daily basis?
11. Is there anything you don't like?
12. Is there anything you consider too much?
13. Do you have improvements and suggestions?

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