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LONG PAPER

Constructing a holistic view of shopping with people with visual impairment: a participatory design approach

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Abstract We report and reflect on a participatory design (PD) process in which we engaged with people with visual impairments (PVI) over an extended period of time; these interactions were aimed at understanding and assessing PVI experiences about shopping and assistive technologies. In particular, we examined in detail how PVI conduct grocery shopping with the help of different technologies, and found that activities taking place in the homes of PVI reflect aspects of the shopping activity that are challenging but understudied in prior work. Our participants revealed that identifying products that have run short, itemizing needed products in a list, and organizing newly purchased products at home were difficult for them; we also discussed the tools they used and whether the tools did or did not help. We synthesize our findings and explain how the extended PD activities informed our ideas for future design, as well as suggesting principles for PD engagement with PVI participants.

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1 Introduction

Assistive technology for people with visual impairment (henceforth, PVI) is often rooted in a disability ideology that aims to mitigate issues resulting from vision loss [15]. This approach to disability support focuses on the "disability" in and of itself, overlooking the active participation of the very people the designers are attempting to help. Some researchers have recognized and avoided this focus on disability "fixes," for example noting that some consequences of a visual impairment may be the result of a marginalization of PVI and other contextual issues, rather than the "impairment" per se [11, 12, 33, 34]. We build on this alternate view, arguing that PVI's special expertise and well-learned daily social practices are of significant value in collaborative design of new technologies. In fact, the failure to consider the opinion of users early on in a design process is a major factor in why people with disabilities abandon technological support [32]. In our study, PVI are not simply participants from whom we collect data, but rather we treat them as agentic partners with whom we collaborate. We treat PVI's lived experiences with technology as privileged data throughout the research process; this is the only way we learn and co-construct an understanding about their practices that can inform future designs.

Previous studies show that creating a thorough understanding and building a solid feeling of trust takes long-term planning, involvement, and shared design activities by researchers and participants, something that brief episodes of participatory design (PD) cannot achieve [10]. Thus, our

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goal has been to spend time with PVI in an extended fashion, beyond a few design sessions, over the course of few weeks or months. Drawing from a PD engagement that has lasted for over a year, we have been able to closely examine PVI's daily practices and the challenges they encounter with respect to technology use in the activity of grocery shopping. By inviting PVI to play an agentic role in design, including careful investigation of their own experiences with assistive technologies in shopping, we complement previous studies. We offer a holistic lens, looking into the process of PVI's daily shopping-related routines, to investigate and search for ways to strengthen these individuals' needs for independence and empowerment. In sum, we propose that assistive technology designs should consider the *whole* of the PVI shopping experience, which extends from the home to the store and back.

Grocery shopping fulfills basic needs for everyday supplies. The ability to shop independently is unremarkable for people with normal vision; however, independent grocery shopping can be extremely challenging for people with varying degrees and types of visual impairment [11]; shopping depends on many routine skills including navigating in the store, identifying objects on the shelves, obtaining desired items, and so on [30, 37]. Imagine the number of products stocked in different sections and counters of your own grocery store, not to mention the different brands, seasonal displays, and occasional promotions that further complicate the task. Without high-quality vision, PVI must rely on other senses, the assistance of other people or guide animals, or specialized technology that help them to complete their shopping tasks.

Researchers in the assistive technology community have developed multiple tools to support the sub-tasks of grocery shopping. These include tools that help PVI navigate around the store and aisles [4, 16, 19, 20]; text recognition tools that assist processing labels and information on products [22, 23, 28]; and tools that refine the process of pinpointing items on shelves and obtaining them [18]. The majority of this previous research has focused on mostly salient activities in shopping, that is, the tasks that occur in the store.

Given that such a wide range of technologies may be designed to aid PVI's shopping routines, their role as agentive actors in the iterative process of design and refinement is critical. Instead of allowing technological assistance to shape PVI's shopping routines, we should reverse the relationship, considering instead how PVI's interests, needs, and potential appropriation of existing technologies can inform design and tool use [21, 27, 36]. From a disability-research or a medical-model perspective [11], designers are oriented toward building interventions that mitigate deficiencies, especially in the case of PVI, as their visual deficiencies are particularly striking. The design rationale for assistive technology should not only be to mitigate deficiencies (ameliorative design), but also to capitalize on the strengths of PVI in a way that supports an individual's full and functional integration in everyday social contexts (affirmative/positive design) [3].

In the spirit of designing *with* PVI, we conducted in-depth interviews, field observations at grocery stores, and home visits over the course of over a year. Under the broad umbrella of human-centered design, we initiated the first phase of an extended PD process wherein PVI, as a primary group of stakeholders, assume the dual roles of informants and analysts regarding their current shopping and technology practices; this phase will be followed by one wherein they assume the role of design partners to envision future prototypes. Through this multifaceted and extended engagement with PVI, we learned that shopping is not just what takes place in a store; the challenges PVI face at home are equally difficult and a salient part of the overall experience. Thus, we propose a holistic view of shopping by PVI that includes shopping trip preparation as well as organization of bought items at home. Our study investigates the broad challenges PVI face in grocery shopping, as well as how current technologies have been appropriated; these findings suggest design directions for future work. Our findings complement prior work by characterizing shopping as a holistic process, identifying previously misunderstood challenges that PVI face within this broader view, and calling for future research and design attention. We offer the technology appropriations that PVI have already implemented as a starting point for capitalizing on current strengths and considering future designs.

2 Related work

According to the Center for Disease Control and Prevention (CDC), visual impairment[1] refers to a functional limitation to the vision system that is beyond what can be corrected; this includes loss of visual acuity, double vision, perceptual difficulty, visual distortion, inability to see in light, inability to see, or a combination of these difficulties. When people have a complete lack of light and form perception, they are considered totally blind (NLP, no light perception). We use PVI to refer to individuals with any of these limitations identified by CDC.

People with different degrees of visual impairment may encounter different types of challenges in grocery shopping, such as preparing a list of what to purchase, navigating to or within aisles in the store, or identifying and selecting items from the shelves and other display furniture. To address

[1] http://www.cdc.gov/ncbddd/developmentaldisabilities/casedefinitions.html.

these challenges, a wide range of assistive technologies have been designed, from low-tech walking canes to high-tech digital sensing devices. The most effective assistive technology depends on a PVI's degree of visual impairment and personal preference. In the observations and analyses presented here, we have focused on PVI who are *blind with no light perception*, what they perceive as challenges in the entire shopping experience, and what technological tools they use to deal with them. We turn next to a review of specific challenges and technological solutions provided to address them.

2.1 Challenges in grocery shopping and technological assistance

Some of the sub-tasks in PVI grocery shopping include list preparation, transportation to and from the grocery store, finding items in the store, and paying for purchases [14]. Most research has focused on in-store tasks, for example how to support navigation to and from aisles, or identification and acquisition of items on shelves.

2.1.1 Item identification

People with complete vision loss often use braille to read or identify items using the haptic sense [30]. Some items have braille labels, which allow PVI to learn about the item; unfortunately however, not every product has braille labels. This is particularly problematic when one product has a shape similar to many others, for instance cylindrical cans of food. The cross-product shape similarity clearly increases the difficulty in distinguishing among types or even brands within a product type. Even worse are cases where the product is new and never encountered previously.

Multiple technologies have been developed to help PVI identify items that do not have braille labels. Optical character recognition (OCR) translates scanned handwritten or typewritten text into machine-encoded text or radio frequency identification tags (RFID) can be used to identify or track tagged specialized electronic information attached to objects [22]. The resulting texts can be presented aurally through devices like mobile phones so that a PVI can access the product information. Barcode readers that scan barcodes on the products are also used to identify products and retrieve related information [20, 22, 26].

Despite the support for item identification, there are numerous difficulties for a PVI to shop independently. For example, OCR has several limitations, e.g., that it best supports English text and it may not fully recognize handwritten cursive writing [30]. Also, the use of RFID requires a well-constructed database and the deployment of the sensors for PVI to access categorized items [38]. Uncategorized or new items in the store will not appear on such a system. Serendipitous shopping is thus difficult if the technology does not support recognition of items displayed on the shelves [22, 39]. In our study, we investigate how PVI perceive technological supports of item identification as part of their holistic shopping experience and what they consider to be limitations on their use of current tools.

2.1.2 Navigation

Liu [23] identified several issues in outdoor navigation, relating specifically to orientation and mobility challenges. Walking canes, human guides, or guide animals are commonly used for general outdoor navigation. Smart phones that implement GPS technology and audio guidance can also support orientation to and from points of interest, such as the off-the-shelf applications BlindSquare[2] or Ariadne [29]. GPS-based systems have several limitations, including less accurate support for indoor navigation, demanding cognitive capacity by engaging multiple senses at once, possible interference with situational challenges like weather or crowds, and a high threshold in terms of implementation across a range of cities or countries [1, 37]. While the support of outdoor navigation has started to consider issues relating to environmental awareness, such as providing opportunistic detours for serendipitous discovery [2, 25], such context-dependent or interest-based suggestions are not commonly provided by in-store navigation tools, perhaps constraining PVI from full engagement in the shopping experience [39].

When PVI shop for groceries, going from home to store is not the only navigation challenge. In-store navigation is demanding and complex, as it involves locating items from specific aisles or finding items in different sections [24]. RoboCart uses RFID readers to track tags scattered in store so as to direct PVI from aisle to aisle [20]. A smartphone that reads QR codes on the items or the shelves, or white canes that implement RFID readers can also give directions [23]. BlindShopping supports aisle navigation and product search, identification, and selection with RFID and audio [24]. However, for in-store navigation to work, technology such as servers, Wi-Fi, or RFID tags must be in place.

Alternatively, the use of computer vision, laser, or ultrasound sensors may address the implementation issues associated with RFID tags and QR codes. GroZi is a design that relies on computer vision through a portable camera attached to a wearable glove to recognize the products and the environment in store [28, 38]. The system uses haptic and audio feedback delivered by the gloves to direct PVI. Computer vision also supports spatial perception, especially the depth dimension. Researchers have developed several applications to support distinguishing colors, signs, or face value of bills

[2] http://blindsquare.com/about/.

using computer vision [23]. With the assistance of a built-in map and a depth-sensing camera, GIST can detect color, human presence, point, and range depth [18]. To extend the range of spatial sense that is possible with walking canes, laser or ultrasound sensors may also be used [1, 31].

Regardless of whether a technology is using RFID or computer vision, tools that rely on these technologies tend to assume that grocery shopping is a strictly planned behavior and that PVI arrive with specific, predetermined shopping goals. However, as routine as grocery shopping may be at times, it is not comprised of simply purchasing a set of items on a list; for sighted people shopping also entails opportunistically encountering new products or brands, engaging in cultural learning about tastes (e.g., what is considered good-quality wine) or different diet regimes (e.g., gluten-free or paleo-diet), or making different choices based on occasional sales [39]. All of these "side activities" are not likely to be supported for PVI with current technologies, as they happen beyond the planning done in advance of the trip, and are very much influenced by what is available at the moment.

2.1.3 Shopping preparation

Previous studies assume that shopping list preparation is a minor or solved activity, or make the simplifying assumption that PVI follow a predetermined list [20, 38]. For example, an assumed workflow is to use PCs with screen readers to aid with list preparation, and audio feedback that enables PVI to select shopping items from a computer database [19, 20]. The assumption that these assistive tools will solve the preparation issue ignores the fact that identifying what is running in short supply at home is not as simple as selecting items from a database. Using the database to generate a shopping list is limiting, in that the database may not be comprehensive and thus will confine users' choices (e.g., produce often lacks a barcode or RFID); it also assumes that the shopper already knows what he or she wishes to purchase on their trip.

Another under-analyzed piece of the shopping experience is the inventorying and organizing of shopped items at home after shopping has taken place. Pre-grocery shopping and post-grocery shopping are important parts of the holistic activity of shopping; however, they are under-discussed in the existing literature. How PVI keep track of their stock, prevent waste of food, reduce frustration when retrieving things, and simplify shopping preparation are central, at minimum, to shopping and, at most, maintaining a healthy way of life.

Speech recognition tools, such as Talking Food Can Lid, Vox Com III, and the Sherlock spoken labeling identifier, can help with identifying items [30]. However, little attention has been spent on matching a shopper's current stock with the labels, which may require considerable work from PVI.

To sum up, gaps identified in the previous literature regarding design goals and their limitations motivate us to explore PVI's actual technology use from a PD perspective:

> How do PVI engage in every step of shopping routine, especially identifying items, preparing shopping lists, and organizing items at home? What are the challenges that they encounter and what strategies and technologies do they use to cope with these challenges? How do PVI's current appropriations inform participatory design so as to enhance equal participation?

3 Methods

For social contexts that involve marginalized users (the activities of PVI are an example), PD can be an empowering method that democratizes the design environment by engaging and valuing the contributions of such individuals [8]. Researchers investigating assistive technologies recognize the importance of PD for PVI; for instance, PVI may work with researchers as practitioner–informants to identify issues associated with a task (e.g., using a map for navigation); as analysts to assess existing solutions; as co-designers to formulate and express new concepts; and as evaluators to test and refine prototypes (e.g., [6, 16, 17]). In prior work, we have argued for the continued engagement of design stakeholders in all of these roles as a project grows and develops over time [10]. Such a PD process allows us to observe PVI's practices from a holistic perspective and to develop trust, which also benefits from a long-term engagement before we introduce design changes into these practices.

3.1 Participants

We have engaged and collaborated with a local chapter of the National Federation of the Blind (NFB), as well as a non-profit organization, North Central Sight Services (NCSS); both are located in a college town in the northeastern USA, and we have interacted with them for over a year. We identified six NFB members who had visual impairment (three males and three females) at the time of our study; we interviewed five of them. In addition to these PVI, the NFB also includes PVI's partners and friends, as well as volunteers. Two of the authors are also NFB members. All authors are participatory researchers of the study and have been involved in chapter activities and interactions with members since the beginning of the study. All interviews were conducted in a one-on-one setting.

Our PVI participants' ages ranged from 25 to 68. Four of the PVI were pursuing a master or doctoral degree at the

Table 1 Participant information

Participants	Gender	Age	Education	Level of blindness	Age of vision loss
P1	M	25	B. A.	Right eye: completely blind Left eye: almost blind, but can distinguish some bright colors and hand movement	Congenital low vision because of glaucoma; became blind at the age of 10
P2	M	32	M. A.	Completely blind (no light perception, NLP)	Lost vision at the age of 19
P3	F	69	(N/A)	Completely blind (NLP)	Had a visual impairment due to open angle glaucoma for a long time and became completely blind at the age of 66
P4	F	32	M. A.	Completely blind but with some light perception	Congenital
P5	M	44	B. S.	Completely blind but with some light perception	Retinitis pigmentosa (RP), became legally blind at the age of 38

University when we interviewed them. One was an employee at the University, and one was a recent retiree. See Table 1 for detailed information about our PVI participants, including their gender, age, educational background, level of blindness, and age when they lost their vision.

3.2 Procedure

We have conducted a mix of in-depth one-on-one interviews (including member checking validations along the way), field observations (where we played the role as either an observer or an assistant), and visits to interviewees' homes for over a year, in an iterative fashion as we established relationships and learned more about the PVI's personal situations. In other words, the research activities reported in this paper were not a one-shot deal; they involved a series of regular interactions and engagement. The aim of these interactions was for the participants to guide us in articulating the entire workflow of shopping as an activity for them. We sought to make PVI's shopping practices as visible as possible by working alongside with them in different contexts, over an extended period of time.

In the field observations, we shadowed participants' shopping routines, including how they prepared and organized at home, coordinated with shopping assistants in stores, coped with many types of challenges and difficulties, and used available technologies to address some of their problems. During our home visits, we closely observed how the individual prepared and organized grocery items at home, asked about the challenges and difficulties he/she faced, and what strategies and technologies were used.

Along with the field observations and home visits, we conducted one-on-one interviews with the participants. With their consent, the interviews were audio-recorded. We followed a semi-structured interview protocol that included questions based on specific incidents of their shopping practices as well as some general topics, including (1) the challenges they faced in their shopping routine, from list preparation, actual shopping experience, to item organization; and (2) specific technologies that they used during each shopping phase. We did not ask about other technologies with which the participants had no prior experience because their everyday practice was our major concern. Thus, what we report in this paper should be viewed as the PVI's usual practice. Also, we did not include online grocery shopping experience in the study for two reasons. First, the Web sites do not always contain a complete list of products carried in the store, not to mention the seasonal products, flash sales, or the experience of going shopping physically are not delivered by online shopping. Second, our interactions with this set of PVI indicated that they are not regular online shoppers.

Each one-on-one interview lasted approximately 50–60 min and took place at either the participant's home or at a grocery store. Due to the fact that we worked with these PVI through a long-term partnership in research, we were able to follow up with brief interviews and member checking if and when we came up with additional questions as we carried out the extended process.

3.3 Data analysis

The interviews were transcribed and analyzed with a bottom-up and iterative approach. One of the authors coded the transcripts first and had back-and-forth discussions with the research team to make sure the themes reflected the integrity of the data and answered our research questions as we worked through the data. Several themes regarding grocery shopping experience emerged from the data, including how participants manage different shopping steps using technological assistance or other strategies, how they perceived challenges and needs at different steps, and their strategic solutions. These themes gradually stabilized with the same themes seen in multiple interviews. We present these themes next.

4 Results

Three themes emerged from our data analysis, each capturing a particularly challenging element of the shopping routine for the PVI. These included detecting what they need to purchase, creating a shopping list, and pantry organization. None of these issues have been well analyzed or discussed in the prior literature, as the majority of previous studies took their focus from the quite salient and directly observable in-store challenges. Our participants did point out that navigation and item selection were two major issues in terms of *in-store* shopping; however, other underlying difficulties noted in our study come from identifying, documenting, and organizing items, all of which are context-specific challenges that take place *at home*. Table 2 summarizes activities, challenges, and current solutions. We now elaborate the difficulties they faced and the strategies they developed.

4.1 List preparation and item identification at home

Preparing to shop by creating a shopping list, however detailed the list may be, can be a constraint on a PVI's opportunistic encountering, learning, and shopping in store. Paradoxically, the major use of the list is to facilitate the process and collaboration with assistants. While it is easy for people with normal vision to prepare a shopping list, whether on paper or in digital form, this step can be a major challenge for a PVI, who may spend as much time and effort preparing a list for shopping as they spend in the store actually shopping. A clear list is important because it not only reduces the burden for a shopping assistant who may accompany the blind person to the grocery store, but also makes the actual shopping efficient. According to our participants, shopping list preparation consists of two tasks: identifying items that are running in short supply at home and documenting or itemizing these as part of a shopping list.

Determining what products are beginning to run out versus what is still fully stocked at home is challenging and time-consuming for a PVI, especially for items like canned goods, boxed cereal, or bottled condiments. Often different products are packaged in similar shapes and styles, and this increases the difficulty of item identification for a PVI. A significant amount of time and effort is spent in this step.

> … there's Orajel for your teeth, if your teeth hurt… And then there's this other stuff that you put on your feet to make sure it doesn't have fungus or athlete's foot, and they're both the same! They're both the same to me, they feel the same, the size of the bottle, everything is the same…Unless they smell very different. (Interviewee 1, Male)

Identifying differences among similar products requires additional effort (obviously this can be difficult even for

Table 2 Summary of interview results

Task/activity	Identified challenges	Current tool use and bottlenecks
Item identification	Confusion resulting from distinguishing products of similar size, shape, or packaging	Braille label, audio recorder, barcode scanners: cumbersome and time-consuming (e.g., locating where barcode is on the product)
	Information like expiration date or ingredients that are not included in the database is difficult to tell	Text/image recognition tools: cumbersome to use and incomplete database for all needed information (e.g., unit price, ingredients, or expiration date). Sometimes users have to manually input the information for these tools to be useful
	Some items—for example fruit, vegetables, dairy produces, meat, and fish—do not come with a barcode	
Itemization and documentation	Documenting a clear list requires switching back and forth between braille and writing systems	A mix of tools like braille, pen and paper, personal computer, mobile phone, voice recorders is used to complete the task: cumbersome and time-consuming
	Having a list can be constraining to actual shopping	
Organization: the beginning and the end	Despite technological support, a lot of efforts and strategies need to be put in re-labeling products so as to prepare for next shopping	Voice recorders, barcode readers, and tags are used. A lot of personal strategies are applied at this step for organization: demanding high cognitive resources

Fig. 1 How a barcode reader was used to recognize the product (left). A can lid with braille label (right)

sighted people, for instance correctly selecting between shampoo and conditioner of the same brand). In order to accomplish the task, participants used sensing strategies ranging from haptic (e.g., braille label) to audio (e.g., audio recorder) (see Fig. 1). For example, image recognition tools may be used, such as *TapTapSee*, a mobile iOS application designed for identifying objects.[3] The participants reported that they took pictures of the objects that they wanted to identify and the application recognized them and gave audio feedback. Barcode scanners were also used in a similar way. However, clearly the time required to enact such transactions adds greatly to the inventory process or even in grocery shopping.

> For some items I am using an app on iPhone called TapTapSee. For example, I might have cans whether its beans or green beans or corn to identify the items, especially cans and packed items I am using TapTapSee. I am just going and checking and sometimes I'm keeping mind if I used the last one, I'm just taking note… Sometimes TapTapSee you might need to take several photos. For example, it can just say can of food but it doesn't say what can it is, so it depend where you took to photos which side of the can you are taking the photo so it can be time consuming. (Interviewee 3, Female)
>
> In grocery shopping I have never used technology. I don't have those barcode readers and stuff. I can use TapTapSee but it's like searching for a needle in pool or something like that. Like which one I am going to take a photo of, I don't know which aisle I should go so it's not working right now. I would prefer something real time instead of taking pictures and waiting for what it is and then taking another picture and waiting. (Interviewee 1, Male)

The use of an identification tool does not solve all the problems. First, it takes time to determine where the barcode is located on an item for a barcode reader or to take multiple pictures to make precise identification for an image recognition technology. Also, the database for the product lookup is not always comprehensive enough to cover all the items of interest, and the update frequency is slow, limiting the amount of information PVI could acquire. Additional information like unit price, ingredients, or expiration date may not be available too. Users had to manually input the product information to the database if unidentified items are detected. Last, some items—for example fruit, vegetables, dairy, meat, or fish—do not necessarily come with a bar code. This makes it very difficult for PVI to learn about the product.

> I don't like to use the barcode reader since it takes too much time for it to locate the barcode and makes me frustrated. (Interviewee 4, Female)
>
> For example, is this beans or soup, or which kind of beans, what the price is, or how heavy it is, or what's the expiration date and stuff like that, and the prices. (Interviewee 3, Female)
>
> Maybe knowing if it's an all-natural, like if it's a grass fed product or not, like beef. If you're getting processed beef or grass fed beef. (Interviewee 2, Male)

Identifying things at home that PVI already own instead of locating them from grocery store shelves appears to be no less easy. A combination of technological support and individual identification strategies is required to solve the issue. Take Interviewee 3 for example; in addition to TapTapSee, she also had a marking system for identifying similar products. Otherwise, constant checking or reliance on memory is needed like Interviewee 4 did.

> …we have powder soups back in Turkey. Those need to be boiled in water. For mushroom soup I was cutting

[3] http://www.taptapseeapp.com/.

this edge and that edge. For mushroom just one edge. For tomato soup, this edge and that edge. For another soup three edges. I was cutting like that very small so I had different packs. (Interviewee 3, Female)

Say something calls for minced garlic I'll double check that I have enough minced garlic…if I cooked with olive oil recently I'll remember "oh yeah that thing was full" but maybe if it's something I haven't cooked with in a while I'll check to make sure I have enough on hand because I like to keep a lot of things, salt pepper, oregano, basil things like that just so I don't have to think about buying those things every time I want to cook something. (Interviewee 4, Female)

4.2 Itemization and documentation for efficient management and collaboration

The purpose of itemizing and documenting a shopping list is twofold: creating a record of what is needed for PVI themselves and making it easier for a sighted shopping assistant, such as a caseworker, a friend, or an associate in a store, to help them. A clear written or typed list facilitates both personal tracking and coordination between the PVI and shopping assistant.

Some interviewees used their computers to type and print out the lists, or sent them through email or text messaging to their smart phones. But not every interviewee was technologically savvy enough to use a word processor to form these lists. In those cases, people had to rely completely on either a shopping assistant to write down the list for them or use their own idiosyncratic methods for creating a shopping list. During one of our field observations at a participant's home, the interviewee showed us how cumbersome it was for him to create his shopping list using a hard paperboard, a piece of letter sized paper, a braille slate, and a pencil. He had to lay and write on a piece of paper on top of the braille slate (see Fig. 2).

What I've done, it's like the Dark Ages… piece of paper. This is a braille slate, you know, for writing braille, and I put the paper in there. (Interviewee1, Male)

There is an important consequence for PVI who go to a grocery store with a relatively specific and clear shopping list: it limits their potential choices to "shop." Interviewee 4 mentioned that reliance on a shopping list means that he will end up with buying just these items, without fully exploring what else might be available to him.

It's just I guess the hardest thing is not buying the same thing every week. Like trying to think up, so you're not eating but being more creative on different dishes and not just like the lazy thing is to buy the same thing that you know every week and then you're eating the same thing every week you know it's kind of not very exciting… because when you're in a store and you have sight you walk around and are like "oh that would be a great idea" but without sight you don't have those ideas pop in your head you know so it would be kind of cool if in a store if they have, let's say they have something on sale say clams and somehow they have the clams in a can. (Interviewee 4, Male)

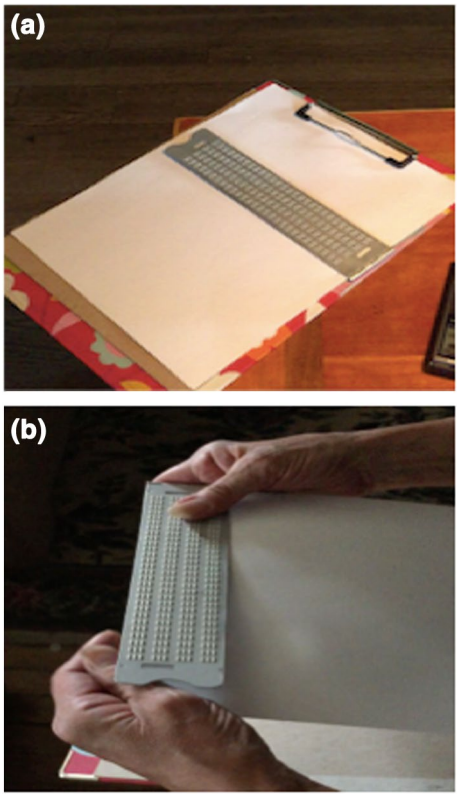

Fig. 2 PVI participant used a braille slate, a piece of paper, and a paperboard to write a shopping list

4.3 Organization: beginning and ending of a shopping activity

Participants identified labeling and organizing one's purchased items independently (i.e., without an assistant's help) as another challenge and used various technologies to help with this. This last step of grocery shopping is very important because it relates to health and safety at home, including easy access to desired items. Also, a well-organized set of products better prepares PVI for the next round of shopping. In this sense, spending time in advance to label or structure one's pantry converts it into a valuable external memory for the overall activity of shopping and food management.

Fig. 3 PVI participant's pantry organization (left). Use of recordable audio labels on the bottle lids (right)

Fig. 4 How a barcode reader was used to recognize the barcode tag on the bottle (left). Reusable barcode tags (right)

Despite the time needed to label the items, whether with braille tape or a custom marking system, our interviewees felt that this is an essential step to complete. One interviewee told us what might happen if she does not mark things properly. She was in a process of making a cake; her 4-year-old grandson was watching. She intended to pour syrup into a bowl; instead, she grabbed the dish detergent. She and her grandson realized the mistake soon enough because they smelled the odor of the detergent and threw the mix away. But such a mistake could endanger her health and her grandson's.

> One time I went to cook with my children, and I squeezed this thing, and they said, "Grandma? I smell soap!" And it was soap, it was dish detergent instead of oil. (Interviewee 1, Female)

In order to avoid such blunders, a range of technologies and strategies were used and adapted as needed for product packages in a range of materials, shapes, and container sizes. For example, one interviewee recycled plastic lids with reused braille tapes on top to label canned goods of the same size and material. She put all the cans with such lids on the same shelf in her pantry. This way, she could easily find the one she wanted in the set of canned products. This also allows her to find out how much of one product she has consumed and what needed to be refilled next time (see Fig. 3). Another interviewee made a slit on the left top edge for one type of item and on right top for another. Other interviewees relied on barcode tags and barcode readers (see Fig. 4).

Despite assistive technology and individual marking strategies, it can still be constraining for a PVI to reach the goal of an organized pantry. Additional steps or cognitive resources for reassurance are required.

> The rectangular jar has the fine bulgur, big jar has the not fine/regular bulgur, or a tin jar has the rice and stuff. So I am using different shapes or I am using labels for the things that are not packed. I am storing things in different shelves or different places so I know, for example, first shelf is for this, second shelf is for that and my husband doesn't change the places of the things. So that's how I am storing…the most difficult thing to differentiate, I haven't labeled them because there are so many of them, are the spices. I am just smelling them. (Interviewee 3, Female)
>
> …mental mapping is kind of like memorizing, but you're using all your, you know, all your senses, remembering. (Interviewee 4, Female)

5 Discussion

Analysis of grocery shopping as a holistic process is absent in previous work. This is not surprising as many aspects of shopping are not easily observable, taking place in private spaces beyond the physical context of a grocery store; these are not bounded activities like finding and purchasing the items on a list. However, they appear to be equally challenging and salient for PVI who have the goal to live an independent life. We propose that these relatively "invisible" shopping activities are of critical importance and central to design thinking in this arena; such information is naturally accessed through the extended participatory methods [10]. At this early point in the project, we reflect on roles played by PVI participants as informants and technology analysts; we also discuss design inspirations drawn from these engagements.

5.1 PVI as practitioner–informants

Our direct engagement with PVI as PD participants produced a holistic understanding of their shopping practices. The PD methods encouraged the PVI to actively help us understand and notice the fine details that comprise their shopping activities, which include identifying which sorts of products are in short supply at home; planning meals or other eating activities for oneself and others; following a specific diet regime; preparing a shopping list according to personal needs; completing shopping tasks in the store; and, after a shopping trip, organizing the purchased items at home.

While targeting specific issues is needed to build technological interventions, we challenge the presumption that shopping preparation and food management are solved problems or less important than the salient challenges of "shopping" in a store. The activities that surround going to a store are often less supported because they occur at home, possibly in isolation, especially for those who live alone. We further argue that treating these activities as solved has a direct impact on the design and usability of technologies aimed at in-store shopping, as such efforts will miss the opportunity to provide an integrated experience. More importantly, such a notion may undermine PVI's needs for equal participation in grocery shopping at minimum and discourage engagement in social activities generally [39]. At this stage, the lessons learned from PVI stakeholders confirm this proposition and identify this broader set of shopping tasks as a research gap in need of in-depth discussion and technological assistance.

Importantly, our detailed attention to shopping practices changed the PVI's personal experience as members of the research project. That is, they came to recognize that research members were not simply wanting to "try out" technologies with them, but rather that the entire team was invested in building a rich shared understanding of everything that shopping means to PVI. One source of evidence regarding this role evolution was a growing willingness to "stand up and testify" about the project, for example at larger project review meetings or as part of project publicity materials.

5.2 PVI as analysts

The PVI participants also revealed how some assistive technologies had been appropriated as part of their shopping practices. In the process of identifying items, our participants emphasized difficulties arising from similar or odd shapes, packages, and materials of some items. Barcode or QR code readers helped process product information, though with these confusing items, detecting such differences required additional effort or senses, such as by smelling, touching, or even memorizing to identify items the PVI *already owned*. More importantly, some pieces of information cannot be easily identified even with assistive tools, for example the freshness of a piece of produce, whether it was organic or farm-fed produce, or an expiration date. While current assistive technologies reduce the trouble and effort experienced by PVI to some extent, they often do not work in concert with other senses that are used by a PVI (e.g., feel, smell). This may result from the fallacy of a design mindset that is still ocular-centric by addressing the most obvious problem (lack of vision), as opposed to building on top of a broader range of existing practices and skills [3, 9]. Given the experiences and practices we learned from PVI in our interview and field study, the importance of using PD to give a voice to PVI in the design of tools meant to support them seems all the more important. That is, PVI need to be able to highlight their capabilities, as opposed to designers only mitigating their deficiencies, which is especially important when the design in question influences everyday activities

like shopping and has a direct impact in their quality of life and broader participation in society.

Another limitation of current tools results from the incomplete database the identification process relies on. The implication of this limitation indicates the need for additional inputting of information for new products in the system; how else will PVI have the chance or capability to acquire knowledge about new products on their own? The underlying constraint of always acting on *known choices* due to the rather fixed set of items that are readily available in a technical support system constrains equal participation by all people and obviates potential learning opportunities for PVI [21]. Moreover, whether or not a given item included in the database reflects any special needs (e.g., dietary) for PVI remains to be addressed.

Next, itemizing and documenting the needed items in a list helps PVI remember what to purchase and helps them to interact with helpers. Aside from the implicit constraints imposed by a predetermined shopping list, the current practices of list creation raised many issues. A wide range of tools are employed in this step, from low-tech paper and pen to high-tech smartphone applications. A phone application may be easy for the technology savvy, as they can use computers or mobile phones to type the list out or audio-record the needed items. However, for others who saw using technology as an additional challenge (or could not afford technologies) codifying the list was burdensome, and the resulting list may not be usable if handwritten or translated from braille. Altogether, these lists created difficulty for PVI in collaborating with the sighted assistant in the grocery store.

List preparation may seem straightforward; however, it requires skills and tool support. The level of completeness of this individual task at home has repercussions for the ensuing collaboration quality, interaction patterns, or even relationship building that PVI may have with the sighted helper in store. One interviewee mentioned that she felt pressured if any of her shopping goals conveyed by the list were unclear, which made her feel like she was imposing on the shopping assistant and forcing them to spend more time with her for purposes of clarification. The sense of dependence and self-perceived disability is increased as a result, and the activity of *shopping* may be reduced to one of simply *buying* things off a list, clearly a step back from the goal to include PVI in daily activities and ensure their rights of equal participation [39]. Even for those using technological support for list creation, the process of sharing and collaboration between PVI and sighted helpers must be considered for future design.

Last, when PVI completed their shopping and returned home, sorting and organizing the items required a systematic routine and tool support for better identification and retrieval. This step is both the end of shopping routine and the start of the next one if it is successful. An effective organization can save wasted time and effort for the next shopping trip. PVI must use a mix of technologies like braille labels, barcode readers, or voice recognition tools. In addition, PVI adopted strategic modifications based on individual preferences and practices, such as reusable tags and braille labels, to make the tools more efficient and suitable. In a sense, current tools provide imperfect solutions to the point that even makes the whole process more cumbersome for PVI to accomplish the task: more dependence on other senses, cognitive resources, or more tools is needed when solving the problems. This is why, for assistive technologies that aim at supporting people with special needs, designers must go beyond simply identifying users with visual impairments obvious deficiencies, instead including them as co-designers in PD activities to empower them to exert control over how the tools are designed/refined to serve their needs, which only they can understand fully. Taking PVI's experiences of technology appropriation and relevant skills in future system design can increase the extent of support and the integration of tools in a PVI's shopping routine [13].

An important caveat is that our PVI participants had higher education levels and socioeconomic status than the general PVI population.[4] As a result, our participants' shopping practices and technology use may not be generalizable. Nonetheless, our findings suggest several design directions.

5.3 Conceptualizing technological support in terms of holistic shopping practices

We learned that technological assistance is needed not only in the store but also at home to support the entire shopping experience. Previous research has tended to overlook this holistic view of shopping because some elements take place in a private context and are not directly observable, or there is the prevailing assumption that a prepared shopping list is required and organizing groceries at one's home is less challenging. With long-term engagement, our PVI stakeholders helped us understand that taking a holistic view is important that also helped to uncover bottlenecks in the use of current assistive technology, challenges of practices at home, and gaps between full support of equal participation throughout the process. Our PVI participants have become key stakeholders in the process, serving as knowledgeable specialists and domain experts who help us to recognize how assistive tools might work for them [7, 36]. We have seen how participants appropriated specific types of technology and how they can be improved to further facilitate PVI's needs. We see design as an emergent and contextualized process; we turn now to several design implications drawn from our PD activities thus far.

[4] http://www.afb.org/info/blindnessstatistics/adults/facts-and-figures/235#educationlevel.

5.3.1 Integrated shopping support

Our PVI participants used various tools and technologies at each shopping stage. For example, in order to identify an item, at least three types of technologies were used, such as braille label, barcode reader, and image or speech recognition tools. The participants pointed out that it was burdensome and costly to own and master all these tools. It is less efficient if a tool only addresses one function (e.g., identification) when a task (e.g., checking if the expiration date is approaching) involves multiple steps (e.g., identifying the product, locating the information about the product, and making sure if it the expiration date is already passed).

As a possible solution to this issue, we call for better-integrated technology assistance that supports the series of inter-related actions that comprise grocery management. For example, one might imagine an intelligent system that tracks pantry contents, sends an automated text or audio message to the PVI when products are running short, and formulates a shopping list. Shopping list can be integrated with store map for the convenience of item location. This design idea aims to relieve the burden of creating detailed lists beforehand by integrating list generation and management with in-store item location and navigation. Another example is a prototype that we are currently developing; it uses computer vision and text recognition techniques to identify products and support in-store navigation and product acquisition [40]. Instead of expecting PVI to use separate tools for navigation and object identification, our prototype design aims to support fully independent shopping, including support for opportunistic goal updates and product discovery. Reducing the number of tools that a PVI must use for performing an already challenging task should be a pursuit of researchers in assistive technology, both to make the managing of devices easier and to increase the flexibility of the tools. It should be our aim to help PVI to live a simpler and more rewarding life.

5.3.2 Positive design

During their use of assistive tools, the participants often engaged other senses, cognitive resources, or custom strategies to confirm information provided by a tool. This has a twofold implication: first, echoing the integration concept above, a better-integrated tool design may address this issue by streamlining each necessary, logical step of an action so as to ease the burdens on PVI users; second, we call for designers to focus more on what PVI users are adept at, in contrast to making up for what they are lacking. The current *deficit-driven* design philosophy highlights what is "normal" and how to make up what is missing; for PVI users, this is the visual sense [11]. For example, barcode readers try to read information on products that a PVI cannot see; yet this creates a side-effect difficulty for a PVI, namely locating the barcodes. This ocular-centric design rationale could put effort into leveling the gaps resulting from the deficiency but may also overlook the opportunities of strengthening what PVI users already excel at, such as their acute audio and haptic sense. For example, the haptic sense might be used to deliver signals for navigation in grocery store aisles, visualization of maps [6], or surf the Internet [17].

A positive or appreciative design perspective may better serve PVI by embedding design work into existing everyday practices and experience. For users with weaknesses or disabilities, designs that leverage strengths may be easier, more pleasant, and more effective for use and adoption [3]. The notion of deficit may be turned into opportunity and leveraged in a positive way for design [9]. Full integration and participation indicates that each actor can engage in social contexts in a way that best suits him/herself. Recognition of a PVI's advantages may be a step forward to the goal.

5.4 Suggestions for PVI engagement in participatory design

Throughout the PD process, we have learned a lot from our PVI partners, and based on this experience, we propose that future assistive technology design, or design in general that PVI use in their day-to-day practices, should take the following aspects into consideration:

- Our focus of holistic shopping practice revealed several unseen and unaddressed challenges faced by PVI. We encourage future studies to consider the whole process of an activity in design so as to identify actual needs and possible technology supports that take place at each stage and as a whole. An analogy that one of our NFB members made illustrates this point well: "it's just like building a house [for PVI], the greatest accessibility comes with all assistive facilities built in from the construction stage. Any add-ons afterwards require additional adjustment.";
- Support distinct activities by shifting the design focus from step based (e.g., identify an item) to activity based (e.g., pantry organization) in order to integrate coherent technological features. Alternatively, designers can think about how to integrate a new tool/function to an existing tool that PVI already own. It cannot only reduce the cumbersome from using many tools for completing one task but saves time and money. Research on public perception of assistive technology pointed out that carrying very prominent tools may elicit social stigma [35];
- Leverage knowledge about what works well for PVI. PVI's expertise and experience are invaluable for informing designs. Designers should not be distracted and consumed by mitigating deficits. For example, if haptic sensation is efficient and accurate in identifying items,

designers should think about how to better support the haptic sense in assistive technology for PVI;
- Engage in PD for an extended period of time. For undervalued and vulnerable participants, such as those who are of lower socioeconomic status or with physical disabilities, short-term engagements may not be sufficient for the designers to fully grasp users' needs and practices. While in general PD work helps empower users and improve design qualities that highlight users' values, long-term engagement can be qualitatively different and illuminating in cases like ours.

5.5 Limitations and future directions

In this paper, we reported on a study of PVI's holistic shopping experience that was conducted for an extended period of time as our PD process. Although we have not yet engaged in concrete co-design, we have already drawn design implications from our participants' experience and appropriations of current assistive technologies. Thus, we have laid the groundwork for design actions that involve and empower PVI, which is a critical move for PD as we address these stakeholders' needs more concretely in the scenario of grocery shopping in an attempt for their full integration and equal participation in social contexts [5]. In the future, we aim to conduct further studies with proposed design prototypes grounded in our current one. In addition, we will expand the scope of these activities to investigate how PVI interact and collaborate with people with full vision to attain different task goals. Allowing all stakeholders, including PVI and those with significant interaction with PVI, to reflect on experiences of activity participation, technology use, and involvement in design can help reach the goal of better technology support and social participation.

Another important issue that should be emphasized is that we reported a study carried out in the USA, which reflected specific practices and cultures. We urge future human-centered and PD studies for PVI to take cross-cultural differences into consideration so as to better inform assistive technological support. We also recognize that there are different types of visual impairments (e.g., blurred, macular degeneration, cataract, diabetic retinopathy, tunnel vision). The current study featured people with complete sight loss, and the results may not be extended to people with other visual impairments. It is important for future studies to investigate practices and needs for participants of different levels of vision loss so as to provide appropriate technological support. Last, we acknowledge that our sample is small but access to PVI is exclusive and they reflect a diversity in age, gender, and technology usage, which provide an adequate basis for us to develop future prototypes.

6 Conclusions

This paper is among the first to consider PVI's whole grocery shopping experience in the hope to inform future designs. In our work, we learned that challenges of grocery shopping did not only take place in grocery store but also at home, including shopping list preparation, stock identification, and pantry organization. Negligence of these challenges or assumptions that these are minor issues could run the risk of preventing PVI from equally participating in social contexts. We present several design implications to address the issues we identified from our PD study, including better integration of multiple tool designs to fulfill actions that PVI want to achieve and recognition of what PVI are adept at in the design rationale. At the same time, we appreciate the level of engagement observed in our PVI stakeholders and look forward to exploring and evolving design concepts with them as our shared PD process continues.

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