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A LOW-COST TOOL FOR GATHERING AND INTERPRETING THE MOBILITY NEEDS OF WHEELCHAIR USERS IN INDIA

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ABSTRACT

Collecting and interpreting customer needs using traditional product development tools can be difficult or impossible when there is a large geographic, cultural, or social gap between the customer and product designer. As part of a project to design an electric powered wheelchair (EPW) for Indians with disabilities, we piloted a new approach to gather and interpret customer needs. First, we distributed cameras to manual wheelchair users at the Indian Spinal Injury Center in New Delhi, India, and asked subjects take photos and write descriptions of accessibility barriers in and around their homes. The film was then processed; photos were de-identified and integrated into an internet-based questionnaire. Individuals with expertise in wheelchair use and design, and home modifications were recruited to participate in the questionnaire where they identified and ranked the accessibility barriers in each of 50 images which were randomly selected from the full database. Thirty cameras were received, yielding approximately 500 photos which were integrated into the questionnaire. A total of 72 subjects from 8 countries participated in the questionnaire. Using cluster analysis, we developed unique groupings for accessibility barriers based on their severity and prevalence. These groupings provided valuable and relevant information to develop and prioritize the design specifications of the EPW.

INTRODUCTION

It is well-accepted that a comprehensive understanding of customers' needs is critical for successful product design [1, 2]. Developing this understanding is a multi-step process which includes gathering raw data from customers, organizing and refining the data, and developing design priorities and product specifications. A host of tools are available to the product designer to help accomplish these steps.

Collecting raw data usually requires interacting with the customers through observations, structured or unstructured interviews, surveys, and focus groups [1, 3]. These tools can be used individually or in combination to develop a comprehensive dataset of customers' needs. Efforts have been made to identify the most useful customer population to use for these surveys and focus groups [1, 4-6], and there are well-structured surveys to help identify important consumer needs [7]. A key for all of these tools is ready access to the consumers—direct interaction between the product designers and end-users is required for focus groups and interviews, while surveys require that the customers can be easily reached through the phone, post, or an online method.

Product designers can also chose from several tools to refine the raw customer data into prioritized design specifications. Ulrich and Eppinger [1] suggest that raw customer statements should be translated into 'customer needs' by the product designer. Needs are then organized into hierarchies and parsed to remove redundant items and grouped into relevant categories for the product. Design priorities and specifications are developed from these organized customer needs to drive the product development process. Specifications and design priorities are often just listed, but more comprehensive tools such as Quality Function Deployment [8] and its variants [9] can be used to evaluate customer needs in light of engineering requirements and the performance of competing products. A key element to all of these tools is the subjective interpretation that the product designer must make to translate the stated customer needs into design features that are required in the design specification. The ability for the product designer to faithfully translate customer needs into relevant design features is critical to the success of the product design process.

Researchers have argued that using 'lead or expert' users in the original needs assessment [4, 5, 10, 11] can reduce the burden on the product designers, since these types of users can provide a more faithful description of their product needs than typical users. Efforts have also been made, especially in the design of computer interfaces, to integrate users into the whole product design process, including translating needs into prioritized design specifications [12], which also removes some of the ambiguity from the process.

When the customers are far away from the product designers, gathering information about customer needs can be difficult and expensive. Likewise, if product designers are not familiar with the social, cultural, economic and other factors at play in the customer's life, faithfully translating customer needs into prioritized design specifications can be difficult, which may adversely affect the success of the product.

The failure of assistive technology devices, such as wheelchairs and prosthetic limbs, designed for developing countries, epitomizes the failure of these critical first steps of the design process. For example, the widespread sale and distribution of the solid ankle cushioned heel (SACH) prosthetic foot was quickly rejected when it was introduced in India. Within a society where squatting is common while performing many daily tasks, the inflexible SACH foot was nearly unusable and was consequently abandoned [13]. An appropriate design was developed by a local physician in Jaipur, India. The "Jaipur Foot" as it is known [13], is aesthetically and functionally similar to the intact foot, and can be produced locally for costs that are affordable to the high and middle wage earners, and are covered by the social-welfare system for the low wage earners.

A similar scenario is occurring with the widespread sale and distribution of hospital-style wheelchairs to developing countries. According to anecdotal and scientific evidence, these devices fail rapidly [13-20], leaving the user without independent mobility, and the purchaser (who is often different than the user) with a sense of lost opportunity and money. In all of these cases, there is no evidence that customer needs were rigorously collected or interpreted.

Successful efforts of wheelchair designs for developing countries come from two primary organizations, both of whom have product designers stationed in the developing region so that more traditional methods can be used to gather and interpret customer needs. Motivation Charitable Trust (Bristol, UK) has designed several wheelchairs for small, medium and large-scale production around the world [21]. Motivation product designers frequently travel to and/or live in the region where the wheelchair will be used, allowing traditional needs assessments to be performed on-site. Concept generation, prototyping and customer evaluations are also accomplished on-site, affording a realistic assessment of how the device will perform in the cultural, social, physical and economic environments of the region. Whirlwind Wheelchair International (San Francisco, CA, USA), uses a similar approach, although they also rely strongly on innovations developed by wheelchair builders who they have trained in the past. Whirlwind started this open-source approach by publishing their wheelchair designs in the 1980's [22] and incorporating design innovaitons introduced by the builders to address variations in material and tool availability in different regions, along with the culturual, social, physical and economic differences.

While the wheelchairs designed by Motivation and Whirlwind are of high quality, the cost-benefit tradeoff is not as high as desired, since this approach requires substantial human and economic resources and has only addressed a small portion of the market need [21, 23]. An 'intermediate' design approach was attempted by Mulholland et. al. [24-26] by traveling to the target region (India) to gather raw data on customer needs, and then relying on surrogate users and other experts to translate the needs data into design specifications. While it is difficult to gauge the potential for this approach based on the outcome of only one case study, the mixed response to the product by the Indian users suggests that the small number of customers who were initially interviewed (n=8) and the use of experts (clinicians, engineers, and people familiar with Indian culture) to translate the customer's needs into design specifications was not sufficient to ensure the product would be successful.

As emerging markets such as India and China grow, so will their demand for modernized products. While good product design practices may be more often the exception than the rule, in some product sectors, such as medical devices, there are standardized techniques that must be followed. To improve safety and efficacy of medical devices, the US Food and Drug Administration (FDA) requires that manufactures follow Good Manufacturing Practices (GMPs) [27] which require, among other things, a comprehensive needs assessment and development of a set of reliable design specifications. If medical device firms intend to design and sell their products into international markets, GMPs need to be adhered to [28]. Thus, especially in the field of medical device design, it is important that tools be available to faithfully capture customer needs and translate those needs into design priorities and specifications despite the geographical, cultural, and societal gulf that may exist between the customer and the designer. Furthermore, tools that can accomplish this without tremendous economic and human resources will afford a competitive edge over those using traditional methods.

The goal of this study was to develop an effective and low cost approach to better understand the mobility needs of potential electric powered wheelchair (EPW) users in India to help in the design and development of an EPW for Indians with mobility impairments.

METHODS

Phase I: Camera Distribution and Collection

The Indian Spinal Injuries Center (ISIC) in New Delhi, India, recruited a convenience sample of 50 wheelchair users to participate in an Institutional Review Board approved camera study. After informed consent was provided, demographic data were recorded (age, gender, disability, occupation, financial background, and rural/urban setting) and subjects were given a disposable camera (28 exposures) with self-addressed envelopes and a small amount of money to cover shipping ($3.00). Directions were given to the subject in person and on a form, instructing them to take photos of the accessibility barriers they encountered in and around their home and work, and in their community. Friends and/or family members were also encouraged to take photos of the subject maneuvering through these barriers. The subjects[1] were instructed to write down brief descriptions of each photo on the back of the lined instruction sheet.

After the cameras were returned to the ISIC, they were developed directly to digital images, transferred to the Human Engineering Research Laboratories (HERL) under an exempt IRB approved by the University of Pittsburgh, de-identified, and screened. Photos that were unclear because of poor focus or lighting were removed from the dataset, and two wheelchair users at HERL (not of Indian descent) were asked independently to screen the de-identified photos. Screeners were asked to view all of the photos in the dataset that did not have text descriptions (provided by the photographers), and mark which the ones that they felt did not include any accessibility barriers. Photos that were marked by both screeners were discarded and not included in the final dataset.

Phase II: Online Survey Development System

We developed an online survey system which would allow subjects to interactively review the photos collected in India. Key features are listed in Table 1 below.

TABLE 1. KEY FEATURES OF ONLINE SURVEY

Back–End Architecture	IIS server, PHP and a MySQL database
Security	Password Protection, Secured Invitation
Survey Tool	13-Question Standardized survey tool, with additional open-ended questions
Image Display	Randomized Non-repeating Order
Reliability measures	Duplicate mirrored images were integrated to evaluate repeatability

[1] For the remainder of this manuscript, subjects in phase I will be referred to as ‘photographers’ to distinguish them from phase II subjects.

Back-End Architecture: The online survey was developed on a personal Windows computer running the web server Apache 2.2 [29] and transferred to an IIS 4 server after development. The interface was written using the Hypertext Preprocessor (PHP) [30] which interfaces with a database stored on the web server. A My Server Query Language (MySQL) [31] database was used to maintain data, and communication between the interface (PHP) and the database was achieved through ADOdb [32], a database abstraction layer. We used ADOdb to preserve the possibility of using other databases (e.g., Access) without major modifications to the PHP code.

User Interface: A subject interested in the study viewed an introduction page, which explained the purpose of the study and presented a model of the questionnaire page. Following the introduction, the subject navigated to a registration page, which recorded non-identifiable demographic information such as gender, age, country, disability (if any), employment status; and familiarity with power wheelchairs and accessibility issues in developing countries. Finally, the subject was asked to enter a unique username and password combination so they could revisit the site and continue the questionnaire at a convenient time. When the user submitted the registration, the information was stored in the database, and a subject-specific random sequence of images was generated.

Upon logging in with their username and password, the subject was presented with the first of their 50-image sequence, a 13-question survey with a series of bullets below each question. Also, two text boxes were presented to record open-ended feedback from the subject. As the subject progressed through each photo, the survey bullets and the text boxes refreshed so that each photo allowed for a new set of responses. Figure 1 shows an annotated screen capture of the user interface (which was also used as the ‘help’ page for the subject).

The user rated accessibility issues on a scale of 1 to 10, where 1 indicated “completely accessible”, 10 indicated “completely inaccessible”, and a 5 indicated that the environment could be made accessible with reasonable modifications such as the addition of a ramp. The questions were drawn from the Americans With Disabilities Act Accessibility Checklist [33], covering such issues as steps, rough terrain, doorway widths, and ramps.

The user was instructed not to answer every question, but rather to choose and rate the accessibility features that were portrayed in the photo shown (un-rated questions remain on a N/A bullet). For example, an image of a flight of stairs might merit a response to the “Steps” question only. After the subject completed the rating and open-ended feedback for a photo, they clicked the ‘submit’ button, and the next image in their subject-specific sequence was displayed. This process continued until the user stopped filling in the survey, or completed their 50 photos. When the first set of 50 photos had been rated, the subject was offered to opportunity to rate additional photos, which were

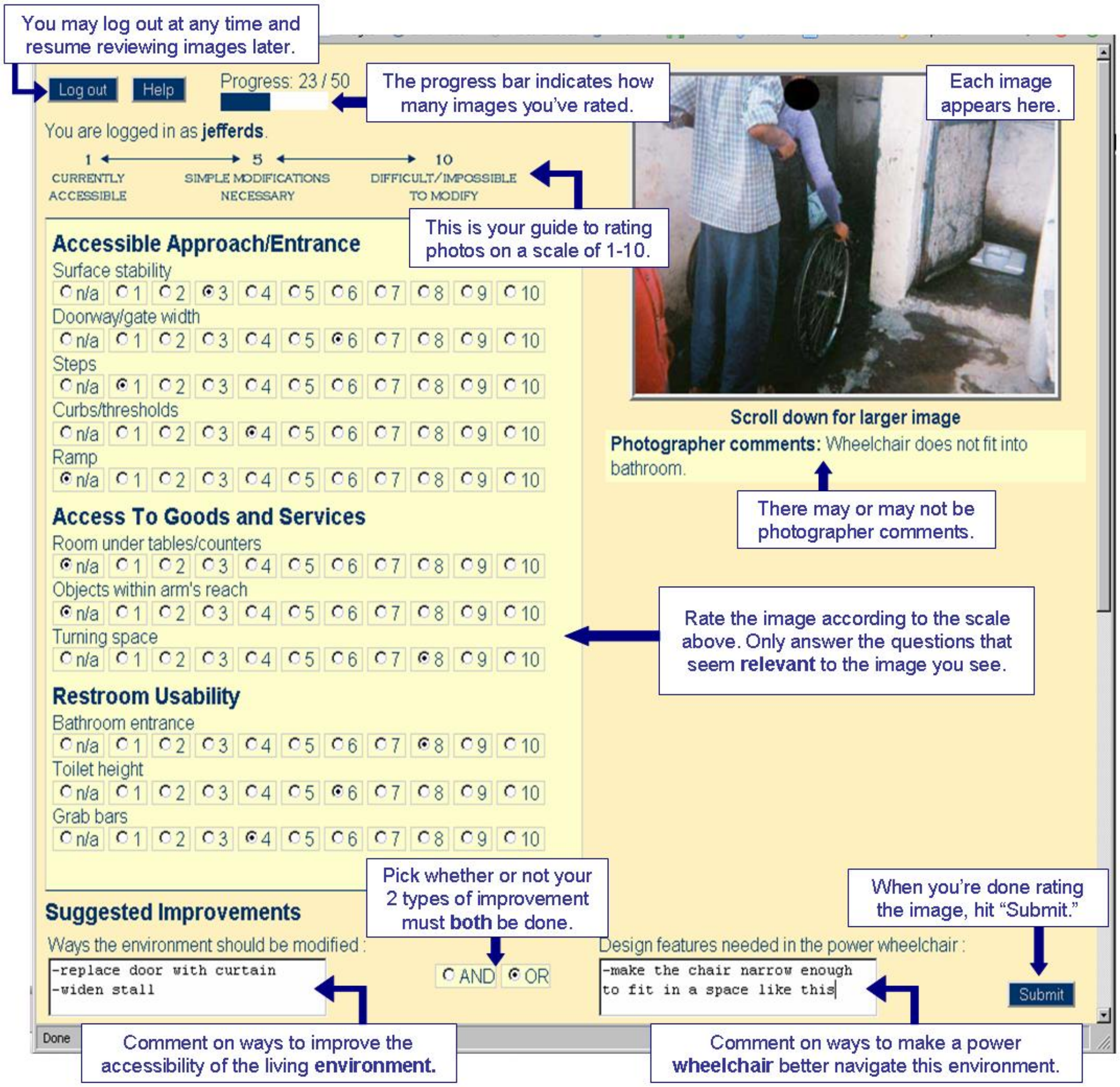

FIGURE 1. AN ANNOTATED SCREEN CAPTURE OF THE USER INTERFACE FOR THE ONLINE SURVEY. THIS WAS ALSO USED AS A 'HELP PAGE' THAT THE SUBJECT COULD ACCESS AT ANY POINT DURING THE SURVEY.

presented in sets of 10 randomly selected photos from the dataset.

Image Randomization: Because rating the full set of photos was too time-consuming for anyone using the online survey, we determined through initial testing of the interface that a subset of 50 photos was a reasonable quantity. To ensure website users were shown an unbiased selection of photos, a unique random sample of 50 images drawn from the dataset for each subject.

Furthermore, since some sets of images from each photographer varied in size, we developed a randomization approach that would not be biased toward selecting images from the photographers with larger sets of data. To accomplish this, the randomization scheme proceeded in two steps—first, a random sample from the photographer ID was selected, followed by a random selection of an image from within that photographer's set of images. Once an image was selected in the random sequence, it was prevented from being chosen again by the randomization scheme (selection without replacement*).* The randomization scheme continued to choose in this manner until it had selected a subset of 47 images (3 images were repeated, as described below).

Reliability: To test *intra*-rater reliability, the first three images in each sequence were copied and spliced into the 50-image sequence at image number 15, 30, and 45, respectively. Thus, the user saw (and rated) three images twice. Repeated images were mirrored horizontally so that the content of the image remained the same but was less recognizable.

Questionnaire Refinement: Two rounds of refinement were performed on the user interface. After the first draft of the introduction page and questionnaire were completed, feedback was solicited from five individuals about the interface. Feedback was specifically requested regarding the registration process, the appearance of the application, and any usability problems encountered. During the second round of refinement, two users completed the entire sequence and gave thoughtful answers as if they were truly participating in the study.

Phase III: Expert Analysis

The photos were transferred from ISIC and analyzed using an online survey system under an exempt IRB approved by both the University of Pittsburgh and ISIC. Subjects were recruited who were knowledgeable about wheelchair use and design, and accessibility issues: wheelchair users and their family members, rehabilitation engineers, service providers (e.g., physical and occupational therapists), and architects who had experience in design and/or modification of environments to make them accessible.

Subjects registered by completing a short questionnaire which collected information on their demographic, vocation/occupation, and wheelchair-related expertise. Each image was presented with an interactive survey (Figure 1) with questions based on the Americans With Disabilities Act Accessibility Checklist [33].

Statistical Analysis: Subject demographics from Phases I and II, and the survey results, which highlight the severity and frequency of the accessibility issues, were analyzed with descriptive statistics in SPSS v14.0 (SPSS Inc., Chicago, IL). To develop unique groupings of the survey results based on the severity and frequency that the issues were selected, we performed a k-means cluster analysis in Matlab r2006 (Mathworks Inc., Natick, MA); we empirically chose to define 3 unique clusters. The test-retest reliability of the questionnaire was calculated using a correlation coefficient. Additionally, we performed a paired t-test ($\alpha = 0.05$) to determine whether the repeated responses on identical images where significantly different. Open-ended survey results were categorized by keywords and the instances of each of the keywords were counted.

RESULTS

__Phase I__: We received 30 cameras with a total of 650 photos from the ISIC which were processed directly to color digital images at 640x480 resolution. After screening was completed, approximately 500 were found to have viable data that displayed accessibility data (e.g., Figure 1). Individuals who returned the cameras included 20 males and 10 females, were 38 (+/-21) years of age, and live in rural (n=13) and urban (n=17) environments.

__Phase II:__ The completed survey instrument, as shown in Figure 1, was the outcome of the Phase II methods. The survey was implemented on our server at the Human Engineering Research Labs (www.herlpitt.org) for subject testing.

__Phase III:__ A total of 72 subjects enrolled in the online study. The registration collected information on several aspects of the subject's disabilities, vocation, awareness of EPW design, and awareness of less-resourced environments (Table 2).

Subjects on average reviewed only 32% of the 50 photos presented; nineteen completed the entire series, and 3 reviewed additional photos. The correlation coefficient of the survey results from repeated images was 0.74, and the null hypothesis-- that the repeated trials yielded the same results--could not be rejected based on the results of two-tailed paired t-test (p=0.712)

The percentage of overall responses (1981) was distributed across the 13 questions with 28% related to surface stability (rough terrain, etc.) (Figure 2, red/oblique hatch). Similarly, subjects rated the severity of the obstacles differently, with 'steps' being the most severe (Figure 2, blue/vertical hatch). K-means clustering was used to define three groupings among the responses, which fall naturally into those with high severity and high percentage, high severity and low percentage, and those with only marginal severity and percentage (Figure 2, horizontal lines above bar graph).

We received over 320 comments related to the wheelchair design, and 570 comments related to home modification, and categorized them by keywords. Selected comments, as well as the number of instances of each of the keywords are reported below (Table 2).

TABLE 2. DEMOGRAPHIC AND BACKGROUND INFORMATION OF THE ONLINE SURVEY SUBJECTS

Parameter	Value	Notes
Subjects	72	Number of subjects
Age	43.6 +/- 13.1 (22-73)	Mean +/- SD, (range)
Gender	40/32	Female/Male
Disability	54	Subjects who either have a disability, or have a family member with a disability
Countries	Austria, Brazil, Canada, India, Philippines, South Africa, USA, UK	Countries Represented
Familiarity w/EPWs	3.2 +/- 0.9 (1-5)	Mean ± SD based on a range indicating no knowledge (1) to expert knowledge (5) of current EPWs;
Awareness of Developing Countries	50	# of subjects reporting familiarity with conditions in developing countries
WC Users	49	# of subjects reporting EPW/Scooter/MWC use (some use multiple devices)
Home Modifications	49	# of subjects reporting home modifications

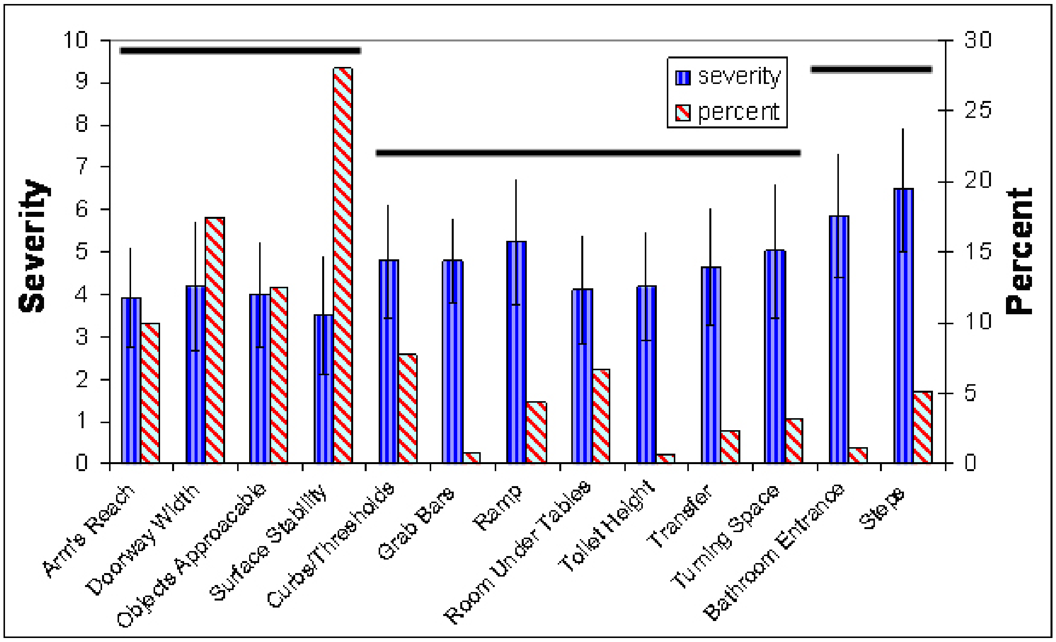

FIGURE 2. SUBJECT RESPONSES TO IMAGE RATING. AVERAGE SEVERITY (BLUE, VERTICAL HATCH) INCLUDES STANDARD DEVIATION ERROR-BARS. PERCENTAGE OF TOTAL RESPONSES (1981) ALLOCATED TO EACH ACCESSIBILITY ISSUE (RED, OBLIQUE HATCH). BARS WERE GROUPED BY K-MEAN CLUSTER ANALYSIS INTO THREE GROUPS, AS INDICATED BY THE HORIZONTAL LINES ABOVE BARS IN THE GRAPH.

TABLE 3. INSTANCES OF KEYWORDS IN OPEN-ENDED FEEDBACK OF SURVEY; SELECTED COMMENTS ARE ALSO INCLUDED TO GIVE AN IDEA OF THE DESIGN AND HOME MODIFICATION ADVICE

EPW Design Comments		Home Modification Comments	
Keywords	**Instances**	**Keywords**	**Instances**
Seat, headrest, armrest, footrest	50	ground, terrain	14
wheel, tire, caster	136	ramp	147
frame, structure	0	railing, handrail	3
Suspension, shocks, springs	28	door	140
size, width, length, wide, long	42	width, size	16
joystick, controller, user interface	4	toilet, sink, bathroom	25
		bed, dresser, shelf, shelves	41

Representative Comments (EPW Design)	Representative Comments (Home Modification)
Minimize overall width of power wheelchair.	Fill in all ditches with pebbles or concrete
Maintain ability for this close diagonal approach and low seat height	Try mounting shelves to wall above knee height in order to use space for turning. Move chairs from under table in order to use space for turning.
Easy transfer from chair to walker, use of chair while wearing braces	The door hinges could be switched to have the door swing outwards allowing more turning room in the bathroom
Removable seat, or recline to lower the overall height of the wheelchair. Accessible tie-down points.	Add a stable ramp so the individual can drive up to the gate. The gate should swing away from the ramp (into the picture).
Able to climb at least 4 inches; able to travel over dirt and rocky surfaces independently	The door must be installed outward and the doorway must be widened. The grab bars and accessible door-knob are needed.
Foam-filled tires to avoid punctures in case any sharp debris is in yard or on road. The wheelchair would also need footrests so that the feet are not drug underneath the chair on bumpy roads. Trust me, it happens!	Plant turf which stabilizes soil with dense roots without deep leaves/stalks, put down wood chips, pave
Power chair should have wide rear wheels with deep treads, wide caster wheels, suspension, and tilt system. Should be able to climb to inch to 4-inch curbs.	Relocation of sink to allow for foot rests. Lowering sink height.

DISCUSSION

Our goal was to gather raw data on the mobility needs of wheelchair users in India, and refine those needs into design priorities and specifications. Performing a typical field-study (e.g., [26]) to collect this data would have been prohibitively costly and time consuming given the diversity and expanse of the Indian Subcontinent. By drawing from the tools used in ethnographic studies [34, 35], and developing an online survey where a wide pool of experts could review the raw photos, we were able to execute a low-cost and effective study to identify, rate, and categorize the types of barriers to accessibility in India. Furthermore, we were able to record several hundred EPW design ideas from experts, providing valuable information to begin the concept generation portion of the design process [1].

Disposable camera distribution was successful in part due to the large inpatient population at ISIC. As patients were being discharged, they were asked to participate in the study and the instructions and cameras were distributed to them as well as a small amount of money ($3.00) to cover shipping costs. The relative percentage of men and women with locomotor disabilities in India is 62% and 38% [36], respectively, which is close to the breakdown in our study (67%, and 33%). The vast majority of individuals with locomotor disabilities live in the rural environments (75%) [36], whereas only 43% of our photographers lived in rural environments. Of the total photographers recruited, 56% lived in the rural environment, but because the dropout rate among those living in rural environments was much higher than the urban dwellers (43% versus 18%) our final urban/rural breakdown did not mirror the distribution in India. We believe that the difficulty of following up with the photographer (via phone or mail) and/or the difficulty of locating a post office in rural environments may have contributed to these skewed dropout rates. In the future, we will anticipate the high drop-out rate and preferentially recruit individuals from rural environments to achieve a more representative sample.

Only 30 exposed cameras of the 50 distributed cameras (60%) were returned to ISIC. We had hoped to achieve a lower overall dropout rate, but following up to remind subjects was difficult once they were discharged, since many did not have phones or mailing addresses. We had hoped to provide self-addressed pre-paid envelopes to the photographers, but due to difficulty with the Indian mailing system, it was not possible to pre-pay for shipping. Instead, we provided the photographers with 150 Indian Rupees ($3.00), and suspect some may have used the money for other goods or services. Only 1/3 (10 of the 30) of the cameras received included written descriptions of the photos, all of which were displayed below the appropriate image in the online survey. Because there were so many images without descriptions, the interpretation of the important parts of the image was left up to the Phase II subjects. In their final comments (collected in the log-off screen), many of the phase II subjects mentioned that they were confused as to what to identify in the photos, which we suspect led the phase II subjects to rate an average of only 32% of the 50 photos in their series. During the user refinement phase of the survey development, we received feedback that the survey may be too long and not give enough guidance on what to rate in the images. We screened the images for content and reduced the target number of images from 100 to 50 in the refinement stage. We also considered adding specific guidance to subjects on what aspects of each image they should rate for the images without text descriptions. We decided not to provide guidance specifically because it would bias the photo ratings to those items the researchers identified as important in the images, which was contrary to the goal of the study to have the experts guide the researchers. In future studies of this type, we will make more of an effort to receive text descriptions of the images directly from the photographers. We may also instruct the photographers to point to the accessibility barrier they are highlighting in the photo with their hand or a specific pointer we provide.

Using the ADA accessibility checklist [33] as the basis for our survey, experts identified a wide range of accessibility barriers in photographs of Indian wheelchair users' homes and communities (Figure 2). While severity of accessibility barriers in different countries may be similar (e.g., steps are severe in all environments) we assumed that the frequency of each barrier differs significantly. For instance, it is likely that surface stability is not the most frequent barrier in and around the homes of wheelchair users in urban United States or Europe since sidewalks are typically paved. In addition to design ideas provided by the subjects participating in the online questionnaire, the frequency of the accessibility barriers can be important information to consider when designing AT for developing countries—the most widely appropriate device would be able to accommodate the most prevalent accessibility barriers. While some of the rating results (Figure 2) were expected, we were surprised to see the low frequency of steps and stairs (5.2% of the responses), given that accessible buildings and homes are not prevalent in India. Based on our results wheelchair users may preferentially choose houses and community paths that do not have steps, and thus they did not appear to be a major issue for the photographers.

The severity and frequency results provide insight into the accessibility issues that wheelchair users face in India. Knowing this information allowed us to prioritize the design specifications for the EPW. In general, if a design addresses the mobility barriers that are most frequent, that design is likely to be more widely appropriate for the user. We interpreted the *severity* of an accessibility barrier as how technically challenging it would be to design an EPW to overcome that barrier. Thus, designing an EPW which can navigate a frequent *and* severe accessibility barrier may be a difficult design challenge, but it would significantly increase the number of users who can benefit from the device.

To prioritize the accessibility barriers, we used k-means clustering [37] to categorize the severity and prevalence data into three unique groupings (Figure 2, horizontal lines). The first group contains highly frequent, but relatively innocuous accessibility barriers. Overcoming these barriers should not be a significant design challenge, and would result in a more widely useful EPW. The second grouping includes barriers rated as moderately severe *and* moderately prevalent; this group may contain the most important and challenging accessibility issue to address in the EPW design. The third group includes barriers rated with high severity but low prevalence. Given their rare occurrence, an EPW design may not need to address these issues, but they should be discussed with any potential EPW user during the service provision process.

The correlation between test-retest ratings was high (0.74) and we did not find a significant difference between the repeated ratings. The most common method to gauge reliability is with a interclass correlation coefficient (ICC) [38]; In our case, since each subject did not rate an identical set of photos, calculating a between-subjects error rate would not have been appropriate. In the future, we may have all subjects review a few of the same photos to permit the ICC to be calculated, since it is a more traditional measure of repeatability.

It is encouraging that we recorded so many open-ended suggestions for the EPW design features and home modifications. At the current stage of research, we have categorized these responses using keywords, and are working though the data to distill it into specific design ideas and important home-modifications that may be necessary.

This type of online tool can be used throughout the design cycle. In the initial stages of the design project, when a needs assessment must be performed, a study like the one described here can be very useful to gather and refine customers' needs, and prioritize design criteria. Such criteria can then be integrated into tools such as Quality Function Deployment [8, 9, 39]. After the initial design criteria have been developed, and generic designs have been developed, an online tool like the one descried here may allow experts to provide further guidance on the design—such as picking specific features.

The methods developed in this study are related to user-centered and participatory design (PD) approaches used most commonly in the design of computer interfaces [12, 34, 40-43]. All of these methods include the user, to varying degrees, in the design process. The principles of PD suggest that the designers (engineers, computer scientists, etc.) operate and are comfortable with a certain domain of technical development and design tools. Likewise, the end-user of a product also operates in a 'user' domain where he or she has specific tendencies, needs, and desires. PD offers tools to the users and designers to operate in a 'third' or 'hybrid' space where their domains of expertise may or may not overlap [41]. The ultimate goal is to streamline the development of products so that they can be optimally designed to meet the users' needs and desires. The risk of leaving the users out of the design process can result in costly and time-consuming redesigning and a host of other issues. In one example, Bravo [44] demonstrated the high costs on the health and efficiency of clerical workers when they are not included in the design of their own work-stations.

In PD and user-centered design, a user is considered to be the expert on his or her own needs and desires. In the study described here, we have split the *users* into two groups: those who photographed their environments in India, and those who rated the Indian photos. We considered the photographers experts on the accessibility barriers they face, but because EPWs are so rare in India, we could not expect the photographers to have enough background in the technology to provide actual design advice. Instead, we recruited a second group of *users*—consumers in industrialized countries who are familiar with the current and past EPW designs on the market, and would have some understanding of the technical boundaries of the devices.

We plan to expand this research approach in two ways. First, we intend to distribute disposable cameras in several sites around the world to better categorize the accessibility barriers in both developed and developing countries. Second, we plan to introduce actual design tools into the online survey, so collaborative design can occur between the photographers, and the subjects viewing the photos, and the researchers. The broad-reaching goal is to develop tools where we can put collective expertise and motivation to work to help design improved mobility devices and AT for less-resourced environments.

CONCLUSIONS

This study helped guide and inform our EPW design, which was subsequently tested with Indian subjects at ISIC, and was well received. The cluster grouping of the mobility barriers (Figure 2) provided valuable information to focus our EPW design criteria on the most prevalent barriers that were noted in the photographs. Without these groupings, we may have spent valuable design efforts on trying to permit the EPW to overcome less prevalent barriers (e.g. steps).

While these clustered groups provided focus for our design efforts, there is a substantially more information needed to develop a comprehensive set of design criteria. The open-ended comment boxes provided one source for this (Table 3), but distilling it into a set of design criteria was a difficult task because of the quantity and variety of comments. Also, by design, this survey only focused on accessibility barriers, and thus would not cover the spectrum of design requirements that a user may have, such as those related to usability, aesthetics, and comfort, etc. Broadening the technique we describe here to help gather these additional design criteria would help improve and streamline the process for low-cost remote design.

One method to broaden the scope of this technique, and also allow for it to be applied to a wide range of device design is to enlist the help of the 'experts' (Phase III subjects) at the beginning of the research to help define what set of design criteria is necessary for a given product. In the context of this study, these experts may have suggested to have users in India take photographs of additional items (related to usability or aesthetics) and also respond to a set of questions about their preferences and mobility goals. Using this 'expertly designed' request for information, users could be queried remotely, and their responses reviewed.

As described in the discussion section, the approach we took, and the one described immediately above has its roots in participatory action design. As we begin to enlist more individuals to help develop the appropriate set of design criteria (essentially helping to design the research project), our approach become similar to 'crowdsourcing' [45, 46] which is a recent phenomenon facilitated by the internet and other low-cost communication venues (e.g. Twitter). We believe that there is 'wisdom in crowds' as crowdsourcing proponents argue. The difficult task is how to leverage that wisdom and focus it on a particular problem. In design efforts, we believe a several-step process may be necessary. First, 'expert' crowds can be used to help define the appropriate set of design criteria which need to be identified, and the best technique to gather this information. Subsequently, the 'crowd' of users need to be queried, and their responses reviewed and distilled into design criteria.

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