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Development of a method for evaluating accessibility of medical equipment for patients with disabilities

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ABSTRACT

Objective: The purpose of this study was to develop a method for evaluating accessibility of medical equipment for patients with disabilities.
Methods: The researchers reviewed videotapes of patient-participants with various physical and sensory disabilities using different types of medical equipment. For each of 11 videotapes, four observers independently identified and documented access and safety barriers, such as physical, sensory, cognitive, and environmental barriers. Inter-observer variability for identifying barrier presence was assessed with kappa statistics for pairs of observers.
Results: A list of 10 access and safety barriers was developed through an iterative consensus process, which identified design features of medical equipment that presented difficulties for participants with disabilities. The list is useful for identifying and categorizing accessibility problems found in equipment. While reliability of barrier identification was substantial or moderate for some barriers, reconciliation of barrier events identified by multiple video observers is recommended for optimal results.

1. Background

Inaccessibility of medical equipment to patients who have disabilities is a critical impediment to equitable provision of healthcare services. Patients with disabilities report that they have difficulty effectively using a range of medical equipment, particularly examination tables, radiology equipment, exercise and rehabilitation equipment, and weight scales (Story et al., 2009; Winters et al., 2007b). Significantly, these populations may be at increased risk of injury from falling during the process of transferring their bodies onto the equipment and while on equipment (Nevitt et al., 1989; Tinetti et al., 1988).

The purpose of this project was to develop and evaluate a method for studying the accessibility of medical equipment for patients with disabilities. Conventional human factors and ergonomics tools, while valuable, have not been tailored to this goal.

Task analysis is a common tool used to study the physical and cognitive demands of a job. It involves studying the actions of participants and their interactions with the equipment and environment associated with a task, such as participant performance, postures, and motions against time. Behavior can be described in relation to the physical, sensory and cognitive demands of tasks (the motor, visual, auditory, tactile, perceptual, memory, and decision-making abilities and skills required), as well as error rates and time taken to complete tasks. The results may be used to define specifications for equipment design and training of personnel (Chengalur et al., 2004). However, accessibility concerns are not explicitly considered during classic product design or evaluation processes.

One negative aspect of the task analysis approach is that time-based metrics are not always appropriate, because for tasks that are not time-critical, a common accessibility accommodation is to give the user more time; indeed, for certain telecommunications and information technologies this type of accommodation is required by law. Also, some individuals with disabilities find alternative strategies to complete tasks, making comparisons between participants more complex.

Usability evaluation is an important part of the equipment design process (Welch, 1998) and has its own set of tools. Previous usability studies of medical equipment (e.g., defibrillators, infusion pumps, needle-protective devices) have primarily focused on safety, usually from the perspective of a medical professional (Adams and Elliott, 2003; Monsieurs et al., 2005; Zhang et al., 2003). For example, methods used to evaluate patient transfer devices for their impact on nurses who use them included expert appraisal and user trials (Le Bon and Forrester, 1997), and

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biomechanical analysis and perceived stress ratings (Garg et al., 1991; Ulin et al., 1997) but not patient perspectives.

As part of their protocols, most usability evaluations include an exposure period that allows participants to become familiar with the device. However, this is inappropriate for medical patients who typically use medical equipment only once or infrequently, not repetitively and often, as medical professionals do. Therefore, the process of evaluating usability of medical equipment for patients should reflect this type of occasional and minimally familiar use.

Another class of human factors and ergonomics tools has been developed by the disability research community. Most often, persons with disabilities evaluate an "assistive" device that is specific to a disability type (e.g., wheelchair, screen reader, hearing aid) (Lenker et al., 2005; Manzke et al., 1998). Few of the tools used for device testing have been evaluated across different types of equipment or different types of disability. Furthermore, few of the tools have been evaluated for reliability.

To date, common human factors usability and ergonomics methods have not been applied to evaluation of accessibility of medical equipment for patients with disabilities. An analysis method was needed that would be applicable to a range of medical equipment that might be used by diverse populations of patients with disabilities. The method should identify aspects of the design of medical equipment that present obstacles or *barriers* for users with disabilities. The barriers would reflect device features that prevent users from using the device safely, effectively, or easily. When desired, these barrier events should then be able to be studied in more detail (using, for example, task analysis techniques).

2. Methods

This laboratory study involved consensus development of a set of access and safety barriers associated with use of medical equipment, videotaping of patient-participants with disabilities while they used medical equipment, and evaluation of the reliability of observer identification of barriers when reviewing the videotapes. The study was approved by the committees on human research at the University of California at San Francisco and Marquette University.

2.1. Barrier list development

A set of 10 access and safety barriers was developed (see Table 1) based on major categories of interactions between humans and devices, including classic distinctions made by the movement science research community between posture, movement and manipulation by human operators (Winters and Woo, 1990). Because access and safety barriers reflect mismatches between the demands of the environment and the capabilities of the user, these interaction categories provide a useful framework for identifying inaccessible equipment features.

The access and safety barriers were grouped by type of barrier but were not ranked and no priority should be construed from their order. The first five barriers were related to categories of human interaction with the device. Barrier #1, orienting/positioning body or device barrier, and #2, body support barrier, involved dynamic and static gross motor movements, respectively. Barrier #3, physical interaction/manipulation/operation of controls barrier, was associated with fine motor movements. Barrier #4, sensory barrier with communication or display, involved visual, auditory and tactile demands of the device and barrier #5, cognitive barrier, involved cognitive demands. These five access barriers were augmented with two safety barriers of particular interest to the U.S. Food and Drug Administration (FDA): use error (barrier #6) and unsafe activity (barrier #7) (U.S. Food and Drug Administration, 2000). The list included two barriers particular to individuals with disabilities: inability to use (personal) assistive technology effectively with the device (barrier #8) and assistance from another person required with the device (barrier #9). One additional barrier (barrier #10, environmental barrier with device) was added during the list development process based on data analysis, described below.

2.2. Participants and tasks

The videotapes used in this project represented a convenience sample of videos that were collected for two previous studies conducted by graduate students associated with the research team. The medical devices and exercise equipment used in the studies

Table 1
Final list of access and safety barriers used in video analysis.

#	Name of barrier	Description of barrier	Example of barrier
1	Orienting/positioning body or device barrier	Involves *dynamic* support needs, such as at set-up/beginning and end of device use, e.g., transferring, body balance or stability, physical obstruction, movement requirements, reaching, strength requirements, etc.	Dental chair lacks handholds to facilitate patient transfer onto chair from wheelchair
2	Body support barrier	Involves *static* support needs for body or extremities without which there is loss of stability or fatigue, e.g., seat, back, leg, arm, head support	Pillow on exam table is too small for patient comfort
3	Physical interaction/manipulation/ operation of controls barrier	Involves physical interactions with controls (e.g., switches, levers), reaching, handling, strength, dexterity, motor control, physical obstructions to hands (or other appropriate body part), etc., during use	Blood pressure cuff is difficult for patient to put on her own arm, with one hand
4	Sensory barrier with communication or display	Involves instances in which device exceeds sensory capabilities for vision, hearing, touch, etc. (e.g., sight lines, letter size, sound volume, ambient noise, tactile features)	Beeps on blood glucose meter are too quiet for patient to hear
5	Cognitive barrier	Involves misunderstanding device, misinterpreting visual cues, memory demands, cuing, language	Patient cannot figure out how to obtain weight on scale with electronic readout
6	Use error	Involves misuse from manufacturer's intended manner of use	Patient tries to read display upside-down
7	Unsafe activity	Involves activity that may put subject or other person at risk of injury	Patient leans on unstable part of equipment
8	Unable to use assistive technology (AT) effectively with device	Involves instances in which device impedes effective use of assistive technology(ies) (AT)	Base of dental chair is too wide and prevents patient's wheelchair from approaching closely
9	Assistance from another person required with device	Must directly affect subject's normal, intended, expected use of device; may be physical (does not include device use tasks normally performed by someone else) or verbal (does not include subject *prompting* needed for task performance)	Contrast on thermometer display is too low for patient to read, and another person must read it for him/her
10	Environmental barrier with device	Involves architectural elements, or auxiliary furniture, or equipment other than device	Furniture within room impedes patient's ability to maneuver

were selected because they were reported to be problematic for patients with disabilities (Winters et al., 2007b). The 12 videos analyzed in our study involved seven devices: an examination table, two power-adjustable hospital beds, two weight scales, a dental chair, and an exercise bicycle (Lemke, 2005).

The studies involved a total of 19 patient-participants who were recruited through local disability support agencies. To reflect the diversity of typical patient populations, the participants had a variety of disabilities, such as major motor disabilities of the lower extremities and/or upper extremities ($N = 15$), balance impairments ($N = 13$), vision impairments ($N = 8$), and/or hearing impairments ($N = 3$). Some individuals had multiple disabilities. No functional assessments were conducted. Individuals with self-identified cognitive disabilities were excluded from participation because the main focus of the studies was on physical accessibility of the equipment.

Participants received a brief (5-min) explanation of the equipment they were to use and the tasks they were to perform as "patients." For example, for the exam table and the bed, participants were asked to get onto the surface and lie down, then sit up and get off. For the weight scale, participants were shown how to use each machine; then they were asked to get on, obtain a weight measurement, and get off. For the exercise bicycle, participants were taught how to use each machine; then they were asked to get on the machine, turn it on, cycle, use a device to obtain a heart rate, turn the machine off, and get off. Participants were instructed to use each device as intended and in the manner that they would normally use it. Participants used each device for two or three trials.

The trials were videotaped using three cameras, two placed orthogonally to the side and the end of the device and one placed at an angle to provide broader context. The video data were stored in digital format to a personal computer using a color quad processor and Synchronized Video Data Acquisition software (SVDA, NexGen Ergonomics, Montreal, Quebec, Canada). Details of the Mobile Usability Laboratory (MU-Lab) used for the study are described elsewhere (Winters et al., 2007a); only the video-based component of the comprehensive MU-Lab process, which includes participant interviews before and after equipment evaluation sessions, is presented here.

2.3. MVTA software

Multimedia Video Task Analysis (MVTA, NexGen Ergonomics) is a software tool for collecting and analyzing observational data. It uses a timeline that synchronizes video, audio, and other data (e.g., from sensors such as EMG or a load cell). Observers can mark "events" within specified "records" on the timeline as they observe them occurring. In a typical task analysis, MVTA is used to mark events such as physical actions (e.g., shoulder flexion) within records (e.g., shoulder posture) as participants perform consistent and often repetitive sets of tasks (e.g., product assembly). For our study, the software was used in a different way, in that the records were access and safety barriers encountered by participants as they used a specific medical device and the events marked were incidents of those barriers (Winters et al., 2007a).

2.4. Observer evaluations of participant actions on videotape

The video segments used in this study contained typical patient interactions with the medical equipment. Due to the heterogeneous nature of the participant population and their disabilities as well as the range of equipment tested, the video segments showed participants experiencing varying types and severities of difficulty accessing and using the equipment.

In order to test the robustness of the video review method, 12 video segments were chosen because they were judged to represent a range of use difficulties. Some video segments contained few incidents of obvious barriers and others contained numerous barrier incidents, some of which were subtle, which served to stimulate discussion among the research team and support barrier refinement.

Using the MVTA software, four observers (one observer did not review the Videos #9 and 10) each independently viewed the 12 video segments to identify and mark access and safety barriers that they identified. The observers were members of the research team: an engineer, a research associate, and two graduate students in biomedical engineering. The two professional observers were experienced at video observation and the students were novices; all had been involved in the research in varying roles. The observers identified the beginning and end of each barrier incident and labeled each barrier (listed in Table 1) with a marker that reflected the severity of the barrier observed (i.e., mild, moderate, or extreme, see Fig. 1; some barrier labels were shortened for display on the computer).

After everyone on the research team had completed a round of analysis by independently evaluating a set of 1–3 videotape segments, the team convened to compare the results. Using a consensus process, the team came to agreement on barrier incidents and modified the definitions of the barriers as needed to improve consistency across observers in subsequent reviews. The team conducted six rounds of videotape review for the 12 videotape segments (see Table 2):

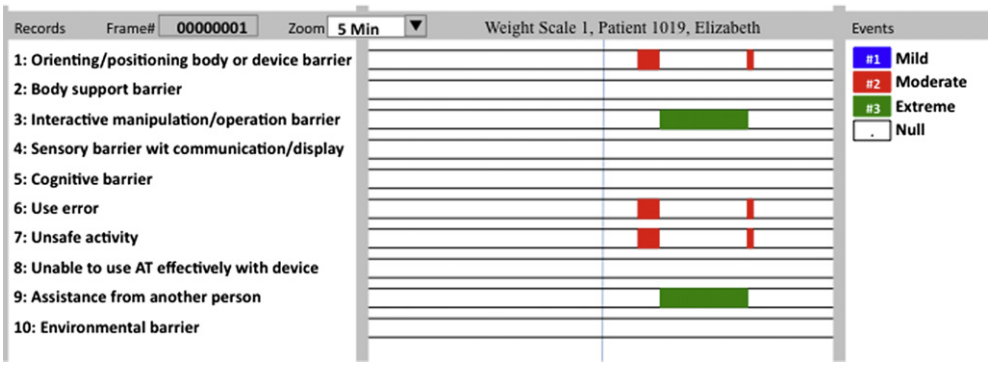

Fig. 1. Example of MVTA data generated for video 8 (redrawn for clarity). The horizontal axis is time. The participant has difficulty getting onto the scale with nothing to hold on to for stability (moderate barrier #1, orienting/positioning body or device barrier) so he grasps the height measurement pole (moderate barrier #6, use error), which is unstable (moderate barrier #7, unsafe activity). Once on the scale, he is unable to reach the controls (extreme barrier #3, manipulation/operation barrier) so the attendant operates the device on his behalf (extreme barrier #9, assistance from another person). When the participant steps down off the scale, he briefly grasps the height measurement pole again for stability.

Table 2
Video data sets.

	Video group 1					Video group 2						
	Round 1			Round 2		Round 3		Round 4		Round 5		
Video #	2	3	4	5	6	7	8	9	10	11	12	
Equipment	Bed1	Table1	Scale1	Bed2	Scale2	Chair1	Scale1	Bike1	Bike1	Bed1	Table1	
Participant #	1000	1002	1003	1003	1007	1008	1019	1014	1015	1001	1003	
Observers	$n=4$	$n=4$	$n=4$	$n=4$	$n=4$	$n=4$	$n=4$	$n=3$	$n=3$	$n=4$	$n=4$	$N=42$
Observer pairs	$g=6$	$g=6$	$g=6$	$g=6$	$g=6$	$g=6$	$g=6$	$g=3$	$g=3$	$g=6$	$g=6$	$G=60$

2.4.1. Pilot review round – video 1

The first round of video analysis used typical task analysis categories as MVTA records, such as: period of body weight transfer, period of extreme posture and period of high sensory requirement. However, this approach did not yield the desired results. Instead, the team decided to use a *barrier analysis* scheme and document instances of mismatch between the demands of the equipment and the capabilities of the particular user. For this purpose, the team generated a list of nine access and safety barriers that patients might encounter while using or attempting to use medical equipment (barriers #1–9 listed in Table 1; barrier #10 was added later).

The results of the pilot video review (for video 1) are not included in this paper and the reliability analysis is based on reviews of the subsequent 11 video segments.

2.4.2. Review round 1 – videos 2, 3, and 4

After this round of video analysis, the team decided to revise the definition of barrier #9 (assistance from another person) to make it explicit that assistance from another person would be ignored if not related to use of the device, that is, if the assistance involved a task or use of a device other than the one being studied (e.g., movement of a rolling bed tray over to and away from the hospital bed being studied). The team also agreed that if the participant used a personal assistive technology (e.g., reading glasses, hearing aid, walker) and the technology was not associated with any difficulty in using the equipment, then no barrier would be marked. In addition, the event list for barriers was modified from a binary presence indicator ("yes" or "no") to a quaternary severity assessment ("mild," "moderate," "extreme," or "null;" however, not all observers used the "mild" category, and these incidents were excluded from the analysis).

2.4.3. Review round 2 – videos 5 and 6

After this round of review, the team decided to add a tenth record to the original set of nine, environmental barrier with device, which involved external obstacles that affected participants' use of the equipment.

2.4.4. Review round 3 – videos 7 and 8; round 4 – videos 9 and 10; round 5 – videos 11 and 12

No additional changes were made to the barrier list (shown in Table 1).

2.5. Reliability analysis

For each MVTA record (i.e., barriers #1–10 in Table 1), each observer's MVTA data set for each video was analyzed to determine whether the observer had identified or not identified that barrier at any time in the record. Agreement or lack of agreement on barrier presence was determined for every pair of observers for every record and video in order to calculate kappa statistics (Fleiss, 1981). Because one observer did not review two of the 11 videos, the data for three pairs of observers included nine videos (#2–8, 11, 12) and the data for the other three pairs included 11 videos (#2–12). The mean value of kappa for each barrier was also calculated. Fleiss's kappa statistic generates a number that represents the proportionate agreement between pairs of observers adjusted for chance, where the value 0 signifies no agreement and the value 1 signifies perfect agreement. The categories proposed by Landis and Koch (1977) were used to provide interpretations for the quality of agreement (see Tables 3 and 4).

3. Results

Across all 11 videos, some barriers were more reliably identified than others [e.g., barrier #5 (cognitive barrier) and barrier #4 (sensory barrier with communication or display), see Table 3], possibly because they were easier to recognize visually. Other barriers were more difficult to reliably identify [e.g., barrier #1 (orienting/positioning body or device barrier)], possibly due to difficulty interpreting the actions of participants, deciding whether the participant experienced any difficulty, and determining the cause of any problems observed. The low reliability of identifying barrier #9 (assistance from another person required with device) was likely at least partly due to disagreement between observers

Table 3
Kappa statistics by barrier across all videos.

Barrier #	Barrier name	Barrier frequency[a]	Kappa values for observer pairs						Kappa-mean	Observer agreement[b]
			1–2	1–3	1–4	2–3	2–4	3–4		
Barrier 1	Positioning	24 of 42	−0.06	0.18	0.65	0.27	0.27	0.27	0.26	Fair
Barrier 2	Support	20 of 42	0.24	0.14	0.03	−0.10	−0.06	0.05	0.05	Slight
Barrier 3	Interaction	11 of 42	−0.04	0.73	0.30	−0.36	−0.16	0.40	0.14	Slight
Barrier 4	Sensory	11 of 42	0.74	0.18	0.79	0.36	0.56	0.18	0.47	Moderate
Barrier 5	Cognitive	11 of 42	0.30	0.61	0.30	1.00	1.00	1.00	0.70	Substantial
Barrier 6	Use error	5 of 42	−0.14	−0.13	1.00	−0.17	−0.14	−0.13	0.05	Slight
Barrier 7	Unsafe	14 of 42	0.11	−0.20	0.42	0.40	0.03	−0.50	0.04	Slight
Barrier 8	Can't use AT	0 of 42							NA	
Barrier 9	Assistance	21 of 42	0.49	0.55	0.29	0.57	0.07	−0.10	0.31	Fair
Barrier 10	Environment	0 of 22							NA	

[a] Barrier frequency represents the number of video-observer data sets that contained events of that barrier. Barrier 8 was not observed in any video by any reviewer. Barrier 10 was not included in the barrier set used for analyzing videos 2–6 and it was not observed in any of videos 7–12.
[b] Categorization of agreement is based on the recommendations of Landis and Koch (1977).

Table 4
Kappa statistics by barrier – comparison of experience level.

Barrier #	Barrier name	Kappa: novice – pair 2–3	Novice observer agreement[a]	Kappa: experienced – pair 1–4	Experienced observer agreement[a]	Agreement difference[b]
Barrier 1	Positioning	0.27	Fair	0.65	Substantial	+2
Barrier 2	Support	−0.10	Poor	0.03	Slight	+1
Barrier 3	Interaction	−0.36	Poor	0.30	Fair	+2
Barrier 4	Sensory	0.36	Fair	0.79	Substantial	+2
Barrier 5	Cognitive	1.00	Almost perfect	0.30	Fair	−3
Barrier 6	Use Error	−0.17	Poor	1.00	Almost perfect	+5
Barrier 7	Unsafe	0.40	Fair	0.42	Moderate	+1
Barrier 8	Can't use AT					
Barrier 9	Assistance	0.57	Moderate	0.29	Fair	−1
Barrier 10	Environment					

[a] Categorization of agreement is based on the recommendations of Landis and Koch (1977).
[b] Amount of difference in agreement, expressed as the number of agreement categories difference from novice to experienced observer pairs.

about what constituted "assistance" with the device (which was sometimes verbal rather than physical) and due to misunderstandings regarding which equipment was peripheral and not the focus of the analysis. The lowest reliability was on identifying barriers #2 (body support barrier), #3 (physical interaction/manipulation barrier), #6 (use error) and #7 (unsafe activity). The low kappa value for identifying barrier #2 (body support) may indicate disagreement on what constitutes "body support" (e.g., need for railings to help maintain balance on a weight scale or need for pillows under the head when lying supine on an exam table) and on when the participant may have needed more support than was provided. The low agreement on barrier #3 (physical interaction/manipulation barrier) suggests that it may be difficult to determine when manual interactions are compromised and when they are simply awkward. The low reliability of identifying barrier #6 (use error) and barrier #7 (unsafe activity) is of particular interest and likely represents differences of opinion on what constitutes an "error" and what is "unsafe."

The experience levels of the observers appeared to have an impact on the level of agreement (Table 4). Agreement was either fair or poor between the novice observers on most barriers and generally higher between the two experienced observers. The barrier for which the difference between the two pairs was greatest was barrier #6, use error. One of the two novices identified use error on three videos (videos #2, 8 and 12) on which no one else identified it, and the two experienced observers both identified use error on one video (video #6), which was not identified by either of the novices.

As shown in the third column of Table 3 (frequency), some barriers were more prevalent than others. The most prevalent were barrier #1 (orienting/positioning body or device barrier, identified in 24 of the 42 video-observer data sets), barrier #2 (body support barrier, in 20 of 42 data sets) and barrier #9 (assistance from another person, in 21 of 42 data sets). Barriers #8 and #10 were not observed by any reviewers, so the reliability of identifying their presence could not be determined from the data.

4. Discussion

A new approach is presented for evaluating the accessibility of medical equipment for users with disabilities. The approach applies a common tool, video analysis, but introduces and defines a set of access and safety barriers that can be identified. The barrier list appeared to be successful for identifying instances of mismatch between device demands and user capabilities. As far as we are aware, this is the first attempt to apply this method to evaluate accessibility or usability barriers across a range of user disabilities and types of medical equipment.

Some types of access barriers could be reliably identified (i.e., barriers related to sensory and cognitive interactions with equipment). For other barriers reliability was low (i.e., barriers related to physical interactions with equipment, use errors and unsafe activity).

Based on post-test interviews with the participants, it appears that no barriers were missed, but supplementary methods may be needed to improve reliability of barrier identification. For example, reliability may be improved with additional observer training. To support this, it may be beneficial to develop definitions of the barriers that include descriptions, as well as video clips, exemplifying each level of severity for each barrier to guide observers as they conduct video analyses. Another strategy may be to review each video clip with the participant immediately following the test session to capture the participant's own perceptions of barriers in order to more accurately identify barriers and understand the sources of difficulties experienced. Best results may be achieved, however, by utilizing a review protocol that does not depend on individual observer data, such as the method recommended by Latko et al. (1997). Their method required that after independently reviewing video segments, multiple observers reconcile any differences in their observations, which would ensure agreement.

The reliability of researchers to identify barriers may have been limited by inadequate precision of the definitions for barriers and incident severity. The differences in reliability between novice and experienced observers seem to support this and suggest that training may improve reliability. On the other hand, increasing the level of detail in definitions of barriers and incidents might decrease the generalizability of this tool or discourage its application to other types of medical equipment.

Another limitation of this study was the relatively small number of videotapes reviewed and therefore the small number and range of disabilities and equipment evaluated, which limited the types of analyses that could be conducted. However, a strength of the study was the diversity of disability types represented among the participants (e.g., motor control, vision, hearing). The proposed approach should be evaluated on a larger array of medical equipment. In addition, larger test participant sample sizes would enable more types of data analysis.

The combination of a broad range of potential patient-user abilities and types of medical equipment presents a high level of complexity that makes observer identification of access and safety barriers more challenging than it is in traditional usability analyses. For this study, we attempted to select equipment to evaluate based on medical equipment that had been identified as problematic by patients with disabilities (Story et al., 2005, 2009; Winters, et al., 2007b). In the future, the application of this method to other medical equipment and to users with other disability types will lead to further refinement of the barrier definitions and the videotape analysis method.

The long-term goal of this project was to develop and evaluate a method for studying the accessibility of any type of medical equipment by any potential user – whether the user is a healthcare professional, lay user, or patient, and with any ability profile – performing any function. Unlike a job in which the worker may be reassigned to a task to which their abilities are better matched, for certain medical procedures (e.g., MRI) a single medical device is often used for all patient-users, who represent a broad diversity of physical, sensory, and cognitive abilities. For this reason, the priority for our approach was to identify areas of mismatch between the demands associated with use of medical equipment and the capabilities of participants, with the ultimate aim of recognizing features of the equipment that could be modified in order to increase its accessibility for users with a variety of disabilities.

Studying barriers associated with access to and use of specific equipment can help identify aspects of that equipment that might be improved through design modifications. For example, provision of properly sized and positioned handholds may make it easier for patients to get onto and off medical tables and chairs and weight scales; patient support surface contours or auxiliary positioning aids may make it easier for patients to maintain postures; volume controls may make it easier to hear auditory information; high-contrast displays may be easier to see; and device labeling that makes operational sequences more clear may be easier to understand and use correctly. The authors believe that the method of barrier identification described in this paper can facilitate the process of making medical equipment, as well as other kinds of devices, easier and safer for diverse populations to use.

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