Universal Design Practices: Development of Accessible Cellular Phones

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INTRODUCTION

In Japan, there were 87 million subscribers to cellular phone services (including PHS service) as of the end of April 2004 (Telecommunications Carriers Association, 2004). In the United States of America (USA), there were some 164 million by the end of May 2004 (Cellular Telecommunications & Internet Association, 2004). And in Brazil, where subscribers surged from 4.4 million in 1997 to 35 million by 2002, it is forecasted to reach 58 million in 2005, according to Anatel, the Brazilian telecoms regulator. Rapid penetration of third-generation (3G) cellular phones is also expected to trigger explosive growth in subscribers who access the Internet and use other information services.

As indicated by these statistics, cellular phones are becoming a common tool for daily communication tasks, including gaining access to the Internet. For this reason, a lack of usability or accessibility in cellular phones not only limits the use of products by users, but also access to information and communication services. Since cellular phones provide access to information and communication services, their ease of use is a key aspect of product design. Just as personal computers (PCs) have quickly become an indispensable tool for improving the quality of life (QOL) of disabled individuals by providing access to information and communication services, prospects are good that cellular phones will enhance the QOL of disabled users as well.

As indicated by the Telecommunications and Rehabilitation Acts of the USA, there is an awareness that societal needs and requirements demand usability and accessibility in cellular phones, PCs, and other IT products (Telecommunications Act, 1999 and Rehabilitation Act, 2001).

To design more user-friendly cellular phones, we have applied a human-centered design process since 1997 (Tomioka, 2002). As part of this initiative, studies of cellular phone accessibility for users with disabilities were conducted in Japan and in the USA. This paper reports a series of accessibility studies we have conducted in the past several years, and describes how the results were incorporated in the latest products recently introduced in the USA market. Also, some important issues and challenges related to practicing universal design that we have faced through those studies are discussed.

USER-CENTERED DESIGN PROCESSES

General accessibility study: Phase I

As the basis for a series of accessibility studies, individual interviews with disabled individuals were conducted both in Japan and the USA to identify needs and requirements in cellular phones. A total of eighteen participants were interviewed: four with upper extremity impairments, seven with legally blind (low vision), and seven with totally blind. To optimize the quality of information gained from the interviews, a focus group of five individuals was implemented in the USA after the individual interviews consisting of one individual with total blindness, one with low vision, and three with motor disorders affecting the upper extremities.

Some of the user needs identified from the interviews are shown in Table 1. These needs are related to several features regarding keypad design, and auditory feedback.

Table 1: Partial list of user needs identified

Feature	Description
Phone size	The size of the phone body was identified as important. Phones considered too thin or those having a small keypad (due to thinness) were not preferred by participants.
Keypad size (key size)	Participants want larger keys.
Key shape	Concave, flat, or rounded at top
Key pitch	Spacing between keys is important.
Key texture	Smooth, rough, or rubber
Key feedback	Sounds when key is depressed; participants wanted tones, clicks, or audio (voice) confirmations
Tactile feedback	Raised dots are appropriate, but placement preferences varied (dot on 5 key or dots surrounding 5 key or dots on 123 keys and 456 keys).
Force needed to depress key	Keys should not be too hard to press.
Key stroke	Key stroke distance should not be too high.
Placement of menu keys	At top or bottom of key pad.
Audio display	Display reads back menus and keys pressed
Electronic key sounds	This function was important to participants, but assignment to keys varied highly.

More specific requirements were derived from all the information obtained from the interviews and the focus group. Table 2 shows only the requirements specifications for key and keypad design.

Table 2: Partial list of user requirements specifications

Feature	User Requirement (s)
Effort required to press keys / Key stroke	Minimize effort required to push keys.
	Avoid the flat-key design. Flat keys were perceived as more difficult to push.
Key pitch	Key pitch must increase (relative to phones provided in this study). Users with large fingers or problems with motor control had major difficulties.
	Maximize key pitch between "Send" and "End"
Key protrusion	Key protrusion must be sufficient to allow user orientation on the key pad.
	Flat or non-protrusive keypad designs should be avoided.
Key shape	Oval key shapes are preferred by users.
	Concave key tops are preferred by users.
Key size	Key size must be increased (relative to phones provided in this study).
	Users require keys of size sufficient to avoid unintentional activation of other keys, and support of raised dots that are large enough and protrude enough to be sensed (by both visually impaired and motor impaired with sensory degeneration in fingers).
Key click	Users require kinesthetic feedback of key clicks (must feel key click).
	Users also must hear key clicks.

General accessibility study: Phase II

The phase I study was intended to extract initial requirements as well as features needing further testing. The purpose of the phase II study was to capture user requirements, based on performance testing and subjective feedback focused on accessibility of the hardware design of cellular phones. The phase I study revealed that keypad design is an important factor affecting the accessibility of cellular phones for users with visual and upper extremity disabilities. Going a step further, the phase II study was intended to evaluate keypad attributes such as key pitch (spacing between keys), key stroke, and key protrusion (key height) that support optimal performance and earn the highest user satisfaction among individuals with disabilities. The phase II study was conducted only in the USA with fifteen individuals: three individuals each with total blindness, legal blindness, severe upper extremity disabilities, minor upper extremity disabilities, and no apparent disabilities.

Four different levels of lateral pitch (10 mm, 11 mm, 12 mm, and 13 mm), three different levels of key stroke (0.3 mm, 0.5 mm, and 0.7 mm) and three different levels of key protrusion (0.3 mm, 0.5 mm, and 0.7 mm) were tested using low-fidelity prototypes. Objective measures such as task completion times and task failures (errors) were recorded, as well as subjective measures such as preference and accessibility. Four different dialings were imposed as experimental tasks.

Figure 1 shows total task completion time and accessibility ratings by lateral pitch and disability. Total task completion time was significantly affected by lateral pitch, disability, and lateral pitch by disability interaction. Dialing times were fastest with the 12 mm lateral pitch, and the dialing times were significantly faster than with the 10 mm and 11 mm levels of lateral pitch (Mooney, 2002).

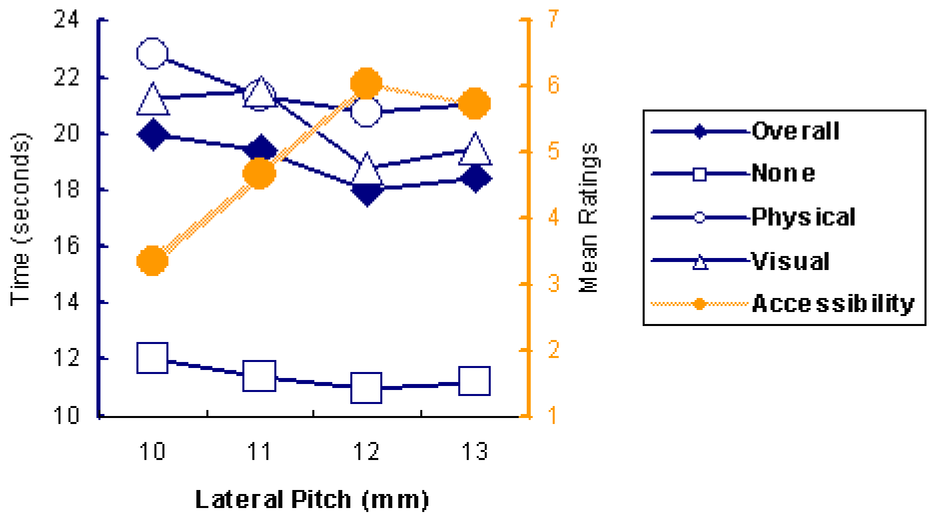

Figure 1. Results of performance testing and accessibility ratings by lateral pitch

Table 3 summarizes the results for all keypad attributes.

Table 3: Summary of performance testing and accessibility ratings

Key attributes	Lateral pitch							
Measures	Performance time				Accessibility ratings			
Levels	10 mm	11 mm	12 mm	13 mm	10 mm	11 mm	12 mm	13 mm
Results	Poor	Poor	Good	Fair	Poor	Poor	Good	Good

Key attributes	Key stroke					
Measures	Performance time			Accessibility ratings		
Levels	0.3 mm	0.5 mm	0.7 mm	0.3 mm	0.5 mm	0.7 mm
Results	No significant differences			No significant differences		

Key attributes	Key height					
Measures	Performance time			Accessibility ratings		
Levels	0.3 mm	0.5 mm	0.7 mm	0.3 mm	0.5 mm	0.7 mm
Results	No significant differences			Poor	Good	Good

Product-specific study

Although basic studies such as these give us a certain direction and yield valuable information for the future development of cellular phones, in-depth study is needed that takes into account actual product development. Thus, studies that closely linked to new product development were conducted during the process of determining hardware and software specifications such as keypad design, audio feedback, and so on.

PRODUCT-SPECIFIC STUDY

Because keypad attributes and audio feedback were identified as the features with the greatest impact on accessibility of cellular phones for users with visual and upper extremity impairments, this study aimed to determine specifications of the keypad and audio feedback features.

Methods

Product interactive focus groups that allowed participants to interact with products during discussion were conducted both in Japan and the USA. Four individuals with total blindness were interviewed in Japan. In the USA, participants included fourteen individuals with total blindness, ten with low vision, and seven with upper extremity impairments.

The focus groups targeted four prototypes under development with slightly different key attributes, depicted in Figure 2. Phones A, B, and C had keys of the same shape but different height (as measured from the surface of the phone body to the top of the key). Key height on phone A was 0.1 mm. Keys on phone B were recessed from the body surface 0.2 mm. This phone also had the body surface cut at about a 45º angle around all sides of the keys. On phone C, key height was 0.3 mm and the body surface around the keys was similarly cut. Phone D was identical to phone C except for the key shape, which was more convex than the other models. Other keypad attributes were the same for all phones, with the key pitch uniformly set at 12 mm based on results of the phase II study.

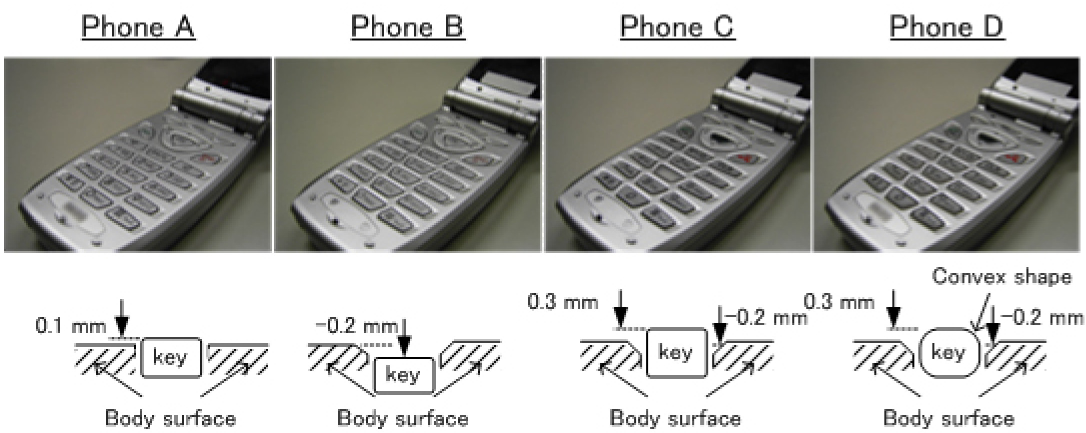

Figure 2. Prototypes used in key attributes evaluation

For the keypad attributes, key heights were first evaluated on phones A, B, and C. Participants were asked to rate each prototype keypad on a five-point scale from the viewpoints of how easy it was to identify the keys by touch and how easy it was to press the keys. Participants were then asked to rank the accessibility of the three keypads. After evaluating the key height, participants were asked to rate the keypads on phones C and D from the same viewpoints as for the key height evaluation in order to evaluate key shapes. Participants concluded by indicating their preference in key shapes.

Before the focus groups, the technical feasibility of audio feedback was investigated. Although "Text to Speech" technology, which can read out text files, became available for some IT products such as PCs and PDAs, we had initially deferred adopting the technology for cellular phones because it required large memory demands and substantial impact on costs. Instead of using Text to Speech technology, a decision was made to equip cellular phones with audio files that can be read out for some on-screen information or navigation. This technique also requires memory capacity, however, so it was not feasible to enable recitation of all information or navigation. Thus, we needed to prioritize the information for audio feedback. Referring to the results of the phase I study, twenty items were selected for the focus groups to prioritize (Table 4).

Table 4: Candidate items for audio feedback

Item	Description
1. Battery charge	Cellular phone tells you that battery charge started or having finished.
2. Battery level	Cellular phone tells you remaining battery capacity.
3. Signal strength	Cellular phone tells you signal strength.
4. Roaming status	Cellular phone tells you if the phone is roaming.
5. Date and time	Cellular phone tells you the date and time.
6. Missed call / New message indication	Cellular phone tells you if a call has been missed or if there is a new voice mail message.
7. Opening / Closing alarm	When you turn cellular phone on or off, a sound rings.
8. Idling confirmation	Cellular phone tells you the phone is idling
9. Key guidance	Cellular phone tells you which key is pressed.
10. Outgoing call confirmation	When you press the "Send" key to place a call, cellular phone reads out the phone number you entered.
11. Ringer type	Ringer type can be selected for each telephone number stored in the phone book so that you can easily identify the caller who was stored in the phone book when receiving the call.
12. Call-history (outgoing)	Cellular phone reads out outgoing calls in call-history.
13. Call-history (incoming)	Cellular phone reads out incoming calls in call-history.
14. Call-history (voice mail)	Cellular phone reads out mail notifications in call-history.
15. Phone book	Cellular phone reads out the telephone number you wish to place a call stored in the phone book.
16. Quick dial	Cellular phone reads out registered phone number or name assigned when you use Quick dial.
17. Speed dial	Cellular phone reads out registered phone number or name assigned when you use Speed dial.
18. Accessibility mode	All accessibility features can be turned on / off by simple operation.
19. Phone book (navigation)	Cellular phone navigates phone book settings by voice.
20. Alarm (navigation)	Cellular phone navigates alarm setting by voice.

In the USA interviews, only individuals with visual impairments participated in this audio feedback part of the evaluation. Participants were given candidate items to be read out with simple descriptions of each and asked to rate levels of necessity of recitation for the items using a categorical scale.

Results

Key attributes evaluation

Subjective data were analyzed using a two-way factorial ANOVA (phone type x disability). As for key height, rating of "ease of identifying the keys" was significantly affected by phone type ($p < 0.0001$) and disability ($p < 0.05$), but not phone type by disability interaction ($p = 0.56$). Post-hoc tests revealed that the ratings were highest with phone C, significantly higher than with phones A and B (Fig. 3). Similar trend was found in the rating of "ease of pressing the keys". Most participants ranked the keys on phone C as the best. It was clarified that the key with a 0.3 mm height with a cut body surface around the key was most accessible for users with visual and upper extremity impairments.

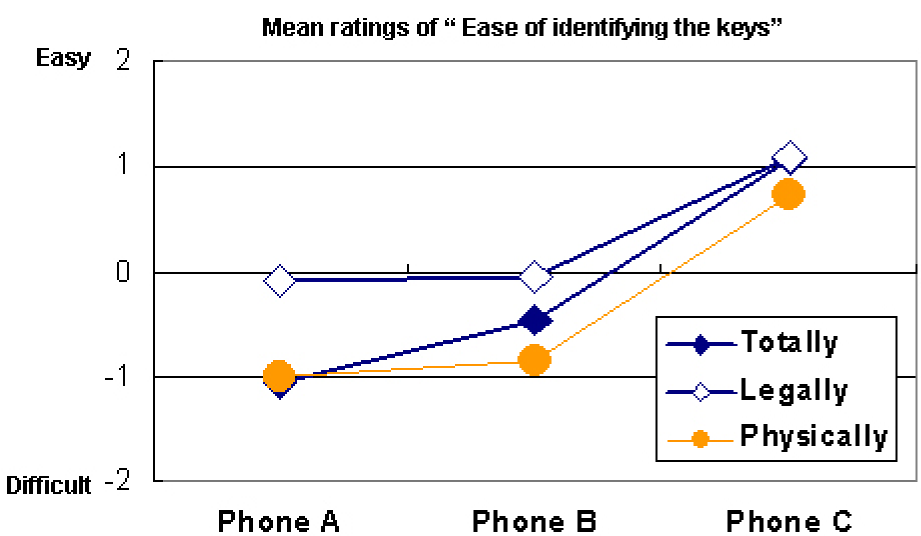

Figure 3. Results of key height evaluation

For key shape, ratings of "ease of identifying the keys" was significantly affected by disability ($p < 0.01$), but not phone type ($p = 0.15$) and phone type by disability interaction ($p = 0.49$) (Fig. 4). Similar trend was found in the rating of "ease of pressing the keys". Although no significant differences were found between the keys on phones C and D in both subjective evaluations, phone D earned higher mean ratings for both evaluations.

The keys on phone D were preferred overwhelmingly among participants with total blindness.

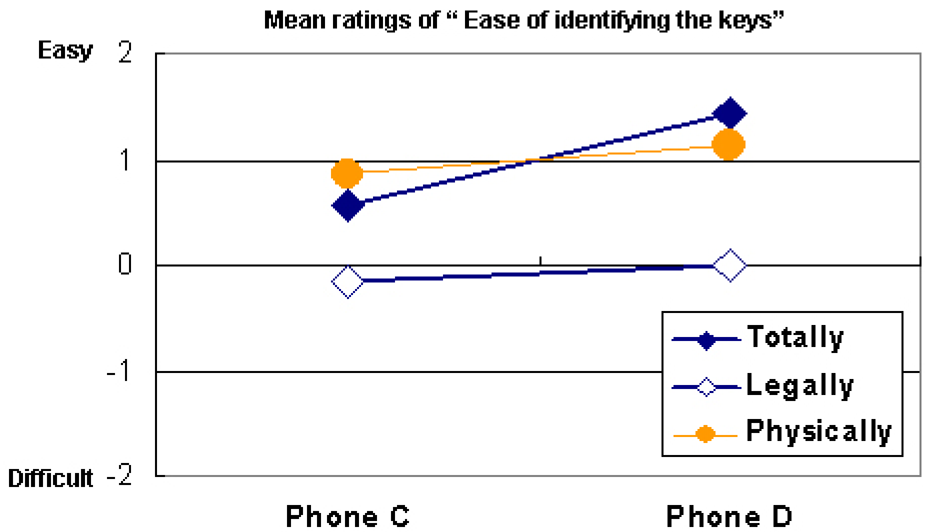

Figure 4. Results of key shape evaluation

The interactive focus groups provided additional information regarding opinions of accessibility of keypad. The opinions consistent across participants were as follows:

- The <5> key must have a "nib" for orientation purpose.
- A nib should be placed in the middle of the <5> key.
- A recessed <5> key may make it easy to identify a nib on the key.

Audio feedback evaluation

Subjective data were analyzed using a chi-squared test. The test revealed that there were significant differences among ratings across all information and functions rated in the focus groups ($p < 0.0001$). Mean ratings for each information or navigation are shown in Figure 5. Overall, participants emphasized the need to notify users of the cellular phone status - items such as battery level, signal strength, roaming status, and missed calls. Participants also indicated the greater importance of reading out call history information, which includes phone numbers the user had already called or the numbers of callers. Most participants insisted that the phone book function have audio guidance for navigation. Besides the need for information and navigation listed in advance for evaluation, the focus groups also cited a keen need for notification of keypad lock mode, phone modes (silent, meeting, and driving), and caller ID.

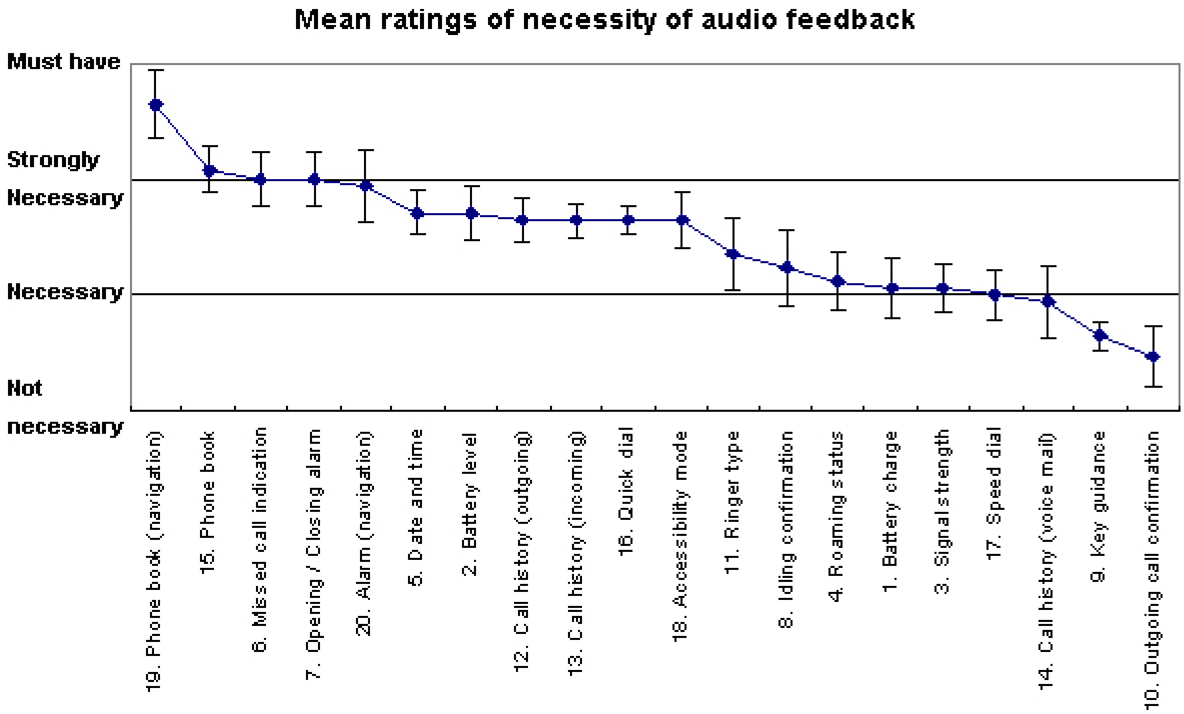

Figure 5. Results of audio feedback evaluation

PRODUCT SPECIFICATIONS

Based on the results of the product-specific study, specifications of keypad design and audio feedback features were determined for our new cellular phone model, VM4050.

The keypad design

The VM4050 keypad was created following the keypad design on phone D. The ten raised, convex keys are in a 3×4 grid apart from other function keys (Fig. 6).

Figure 6. Photos of the keypad on the VM4050

The <5> key is slightly recessed, with a nib in the center. The Talk and End keys also have nibs.

Audio guidance

The audio feedback feature of the VM4050 is called “Voice Guidance”. Focus groups emphasized the need for audio feedback during phone book operations, but it would have been unfeasible to have all phone book navigation read out from pre-recorded audio files. Also, this would have required us to redesign the entire menu structure and navigation to make the phone book fully accessible, which leads to substantial time and cost demands. Under the circumstances, a decision was made to forgo Voice Guidance support for the phone book on the VM4050.

Voice Guidance specifications were designed for maximum support in providing users critical information about the cellular phone through verbal and nonverbal audio feedback. This critical information was selected based on the level of priority determined in the focus groups, and it covers battery level, signal strength, roaming status, missed-call and voice mail notification, and so on. In addition to giving critical information, Voice Guidance also read out the number of an incoming call when users press the Send key while the phone is ringing. To answer the incoming call, the user simply presses the Send key again. Voice Guidance can also read out the number of an outgoing call the same way, and users can listen to call-history information (about calls that were received, missed, placed, and so on). Further details on this feature are omitted here because of space limitations.

DISCUSSION & CONCLUSION

This section presents a discussion of key issues and challenges gained from the process of developing a more accessible cellular phone.

Cost-effectiveness

Ideally, it would be preferable to offer greater accessibility at little or no additional expense. But in reality, efforts to make products more accessible sometimes wind up making them more expensive. After an overall judgment was formed accounting for technological limitations, costs, and other considerations for the VM4050, it was decided to use relatively affordable technology to offer a certain level of accessibility. Text to Speech technology might have made some of its functions even more accessible, but it would have led the cellular phones expensive. In fact, the same task of evaluating cost-effectiveness is faced for many products when all their specifications other than for accessibility are studied as well. Ron Mace described a principle of universal design in this requirement: “The design is useful and marketable to people with diverse abilities.” The stipulation that products be marketable is, for us and other manufacturers, one of the essential criteria in practicing and sustaining universal design programs. But investigating the cost-effectiveness of accessibility features in particular is challenging. What will play an increasingly vital role in this investigation is ongoing research of the type described in this paper and feedback from disabled users themselves.

Design processes

VM4050 specifications were iteratively determined through the series of accessibility studies. In this way, the all steps of the human-centered process were fulfilled as defined in ISO 13407, which standardizes human-centered design (HCD). Specifically, the general accessibility study provided a way to "understand and specify the context of use" and "specify users and organizational requirements," while the product-specific study helped "produce design solutions" and "evaluate designs against requirements." Practicing HCD this way led to development of more accessible products. Ultimately, it also supported more efficient product development.

Universal design is a philosophy and a practice. Practicing universal design entails not only improving accessibility and usability for disabled users, but also enhancing product performance and user satisfaction for users without disabilities. Making products available to as many people as possible is our constant goal. We will continue to practice universal design for products of all kinds through HCD processes targeting the widest range of users.

ACKNOWLEDGEMENTS

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