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ORIGINAL ARTICLES

Accessibility of Home Blood Pressure Monitors for Blind and Visually Impaired People

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Abstract

Background:

The prevalence of hypertension comorbid with diabetes is a significant health care issue. Use of the home blood pressure monitor (HBPM) for aiding in the control of hypertension is noteworthy because of benefits that accrue from following a home measurement regimen. To be usable by blind and visually impaired patients, HBPMs must have speech output to convey all screen information, an easily readable visual display, identifiable controls that are easy to use, and an accessible user manual.

Methods:

Data on the physical aspects and the features and functions of nine Food and Drug Administration-approved HBPMs (eight of which were recommended by the British Hypertension Society) were tabulated and analyzed for usability by blind and visually impaired individuals. Video Electronics Standards Association standards were used to measure contrast modulation in the displays of the HBPMs. Ten persons who are blind or visually impaired and who have diabetes were surveyed to determine how they monitor their blood pressure and to learn their ideas for improvements in usability.

Results:

Physical controls were found to be easy to identify, and operating procedures were found to be relatively simple on all of the HBPMs, but user manuals were either inaccessible or minimally accessible to blind persons. The two HBPMs that have speech output do not voice all of the information that is displayed on the screen. Some functions that are standard in the HBPMs without speech output, such as the feature for automatically setting cuff inflation volume and memory, were lacking in the HBPMs with speech output. These features were mentioned as desirable in interviews with legally blind persons who are diabetic and who monitor their blood pressure at home. Visual display output was large and adequate in all of the HBPMs. Michelson contrast for numeric digits in the HBPM displays was also measured, ranging from 55 to 75% for characters with dominant spatial frequency components lying in the range of 0.5–1.0 cycles/degree.

continued →

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Abbreviations: (AAMI) American Association for the Advancement of Medical Instrumentation, (BGMs) blood glucose monitors, (BHS) British Hypertension Society, (CSF) contrast sensitivity function, (FDA) Food and Drug Administration, (HBPM) home blood pressure monitor, (IPs) insulin pumps, (LCD) liquid crystal display, (MTF) modulation transfer function, (PDF) Portable Document Format, (SQRI) square-root integral, (VESA) Video Electronics Standards Association

Keywords: accessibility, blindness, diabetes, home blood pressure monitors, hypertension, visual impairment

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Abstract cont.

Conclusions:

Home blood pressure monitors are easy-to-use devices that do not present accessibility barriers that are difficult to surmount, either technically or operationally. Two HBPMs with voice output were found to have a significant degree of accessibility, but they were not found to offer as many features as those HBPMs that were less accessible. Recommendations were made to improve accessibility, including the development of visual display standards that specify a minimally acceptable level of Michelson contrast.

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Background

Diabetic retinopathy in the United States affects more than 5.3 million people over age 18 and, by 2020, will affect about 7.5 million persons.[1] Estimates of the incidence of hypertension in people with diabetes are high: 54% of Caucasians, 60.4% of African-Americans, and 65.3% of Mexican-Americans.[2,3] In type 2 diabetes hypertension is often present as part of the metabolic syndrome of insulin resistance and in type 1 diabetes it may induce the more rapid onset of diabetic nephropathy.[4] Hypertension comorbid with diabetes is known to increase the risk of retinopathy, and tight blood pressure control reduces the progression of retinopathy and deterioration of visual acuity.[4–6]

The most accurate home blood pressure monitors (HBPMs) are digital devices that use automatic, upper-arm cuff inflation and an algorithm to interpret variations in blood pressure.[2,7,8] The potential benefits of HBPM use include documenting sustained or intermittent hypertension in the usual home environment; diagnosing "white coat" hypertension, where anxiety contributes to a sporadic high blood pressure reading in a clinical setting; assessing response to antihypertensive medication; improving adherence to treatment; and reducing the cost of frequent office visits for obtaining many blood pressure measurements in the physician's office.[2,9,10] Results of a study showed that hypertension control was significantly more successful in patients who followed a home measurement regimen than with those who did not.[11]

Requirements for blind and severely visually impaired people who cannot see the HBPM screen are speech output that speaks all information presented on the display screen and tactually discernible control buttons. Requirements for visually impaired persons are visually discernible display output and control buttons. For both blind and visually impaired persons, operation of the HBPM must be both easy to accomplish nonvisually and documented in a user manual that is accessible. Print versions of user manuals should conform to existing large print guidelines.[12] Acceptable electronic formats include popular word processor formats, plain text (.txt), web format (html), or Portable Document Format (PDF). Additionally, a Braille operating manual should be made available on request.

Reflective liquid crystal displays (LCDs) that are embedded in HBPMs and other diabetes monitoring technology, such as blood glucose meters and insulin pumps, must have characteristics that allow the displayed information to be accurately discerned by visually impaired individuals. Evaluating the degree to which these displays are usable by visually impaired persons is a critical challenge, as quantifiable standards for designing small-screen LCDs for this population have not been adequately developed. Although vision experts and ergonomics experts agree that the most important characteristics of a visual display are font, contrast, luminance, glare, and hue, and there are broad-based guidelines in the literature, current design practices are instead based on the availability of inexpensive and commonplace LCD technology.[13–15] Furthermore, reliable data on the visual characteristics of the small-screen displays used in today's products are not available.

This study's overall objectives are to evaluate the accessibility of commercially available HBPMs, including display characteristics, and recommend accessibility solutions for future development.

Methods

In total, nine HBPMs were tested. HBPMs without speech output included the HEM-705CP and HEM-757-E from Omron (Bannockburn, IL); the BP-3BT0-A from Microlife (Dunedin, FL) (see **Figure 1**); and the UA-779, UA-767PV, UA-774, and UA-787 from A&D Medical (Milpitas, CA) (see **Figure 2**). The two with speech output were the UA-767T from A&D Medical and the Reizen from MaxiAids (Farmingdale, NY) (see **Figure 3**).

To be included in the test group, an HBPM had to be on the U.S. market with Food and Drug Administration (FDA) approval and be recommended by the British Hypertension Society (BHS). FDA approval requires that the product meet American Association for the Advancement of Medical Instrumentation (AAMI) self-verification standards. AAMI requires that the manufacturer test their own products and report the results of those tests to the FDA. BHS criteria were included because their recommendations are based on independent testing of accuracy rather than self-testing by the manufacturer as is required by AAMI. The BHS recommendation is based on BHS grading and international protocol.[16,17] Only one monitor with speech output, the A&D UA-767T, was identified that met all of the criteria for inclusion. However, because monitors with speech output are of particular interest to people who are blind or visually impaired, a second monitor with speech output, the MaxiAids Reizen, was included in the test group. This extra monitor is the only other monitor with speech output on the U.S. market with FDA approval, but it does not have a BHS recommendation. It was not possible to determine the intent of the manufacturer in regard to obtaining a BHS recommendation.

Data on the physical aspects and the features and functions of each HBPM were tabulated and analyzed. Display font size was calculated by measuring the visual angle, that is, the angle that is created from the top and bottom of the image at a viewing distance of 12 inches to the eye.[18,19] The spatial frequency of a sinusoidal intensity pattern is defined as the quotient of the number of observed repeating cycles (of bright/dark bands) seen within the visual angle, and the visual angle itself as measured at the distance of observation. According to Fourier analysis, a localized two-dimensional (*xy* plane) character of arbitrary shape can be constructed from a two-dimensional integral (over spatial frequencies associated with both axes) of sinusoidal luminance patterns of appropriate spatial frequency and contrast, weighted by the appropriate Fourier expansion coefficient. For a simple character such as an E or 8, a Fourier analysis shows that the vertical (the *y* axis) integrand will peak at the spatial frequency associated with the

Figure 1. Omron HEM-757-E and Omron HEM-705CP: upper row, left to right. Microlife BP3BT0: second row.

Figure 2. A&D UA-779 and A&D UA-787: upper row, left to right. A&D UA-774 and A&D UA-767PV: bottom row, left to right.

Figure 3. A&D UA-767T and MaxiAids Reizen: left to right.

fundamental frequency (here two cycles divided by the visual subtended angle; we refer to this as "dominant spatial frequency"). The dominant spatial frequencies of the display characters were simply estimated assuming two cycles per character (i.e., an E) per associated measured visual angle (in degrees).

Video Electronics Standards Association (VESA) standards were used to measure contrast modulation in the displays of the HBPMs.[18] The HBPM reflective LCD display was illuminated isotropically with 85 cd/m^2 (a typical clinical standard as discussed later), while positioned as close, and as near to normal incidence as possible, to one port of an integrating sphere with a current-controlled tungsten lamp from SphereOptics. The reflected light from the display, propagating through a second (baffled) port on the opposite side of the integrating sphere, was gathered by a 12-inch working-distance Leica Z6 apochromatic zoom microscope. An iris was placed in front of the microscope's objective to restrict the acceptance angle to two degrees. A single-lens reflex digital camera (Canon EOS D30) employing a complementary metal oxide semiconductor detector array was attached to the microscope with standard adapters. The entire apparatus was mounted on an optical rail for ease of focus and positioning relative to the display. A low-frequency Michelson contrast was computed from the measured pixel intensity count across a line, placed along the digitized image of the target character using National Instruments Vision Assistant software.

Task analyses were performed on HBPM blood pressure measurement operations, including cuff placement and assembly and battery replacement. The speech output on the two talking monitors was also tested for speech quality and the extent to which it voices display information.

To acquire information from users about how they monitor their blood pressure and to learn their ideas for improvements in usability, a telephone survey was conducted. Ten legally blind hypertensive or hypotensive men and women with type 1 or type 2 diabetes were interviewed by phone. Among the topics covered in the 20-item interview were background on their level of visual function; patterns of device use; likes/dislikes of the monitoring device; and awareness of HBPMs on the market with speech output.

Results

Physical Attributes and Features

Table 1 shows the physical attributes and features of the HBPMs. All the HBPMs tested were similar in size, ranging from 6.6 × 4.3 × 2.1 to 6.9 × 5.2 × 2.9 inches, and the weight of the monitors, with cuff and batteries included, ranged from 17.8 to 22.1 ounces. Only the Omron HEM-705CP has the ability to print out results for users who would like to keep a hard copy record of their blood pressure and pulse measurements. Utilizing the printout offered by the Omron HEM-705CP, the user can also obtain an average of their readings and a graph of results in memory along with the single printout of the last measurement. These useful records can be reviewed by the physician.

Table 1. Physical Attributes and Features of HBPMs

Blood pressure monitor	Omron		Microlife	A&D Medical					MaxiAids
	HEM-705CP	HEM-757-E	BP-3BT0-A	UA-779	UA-767PV	UA-774	UA-787	UA-767T	Reizen
Size, L X W X H (in.)	4.5 X 7 X 2.8	4.5 X 7 X 2.8	6.9 X 5.2 X 2.9	4.9 X 5.6 X 2.9	4.3 X 5.6 X 2.5	4.3 X 5.8 X 2.5	4.4 X 6.4 X 2.4	6.5 X 4.4 X 2.7	6.6 X 4.3 X 2.1
Weight (oz.) (with cuff and batteries)	19.2	22.1	21.1	18.4	18.3	17.8	19.2	18.5	20.3
Speech output	N	N	N	N	N	N	N	Y[a]	Y[a]
Printout	Y	N	N	N	N	N	N	N	N
Memory averaging capability	N	N	N	N	Y	Y	N	N	N
Fuzzy logic[b]	Y	Y	Y	Y	Y	Y	Y	N	N
Number of users in memory	1	1	1	1	1	2	1	-	-
Number of measurements stored in memory	28	14	1	7	30	30	30	-	-
Operating manuals	PDF	PDF	PDF	LP,[c] PDF	LP,[c] PDF	LP,[c] PDF	LP,[c] PDF	Audiocassette, LP,[c] PDF	MS Word file on CD

[a] Recorded human voice.
[b] Used in algorithm for ensuring minimum necessary cuff inflation volume.
[c] Large print.

Although the tasks of connecting the printer to the monitor and pressing the appropriate button on the printer can be done tactually without the need for vision, the printout is in an 11-point font, which is too small for most people with low vision to read. Also, scanning the printout with popular optical character recognition software did not successfully identify the results that were printed. This Omron monitor also has two buttons for setting the time and date, but that process is inaccessible to blind users because there is no speech output.

All of the monitors except the two with speech output use a feature for automatically setting cuff inflation volume to the minimum necessary level. The two monitors with speech output, the A&D UA-767T and the MaxiAids Reizen, require the user to manually set the minimum cuff inflation volume. The two monitors with speech output also lack the ability to store past results in memory, a useful feature common to all the other monitors. The Microlife monitor can store only one past result in memory, but the other monitors have memory capacities ranging from 7 to 30 past results. Two monitors from A&D Medical, the UA-767PV and the UA-774, have memory averaging capability, which means that they can display the average of all the readings stored in memory, and the UA-774 can store two separate sets of results for two separate users. Only the Omron HEM-705CP displays the record of the date and time.

On six of the seven monitors that have memory capabilities, the user simply presses the memory button and the last measurement is displayed on the screen. Users can scroll through earlier measurements by successive presses of the memory button. On the Microlife monitor, the user presses and holds the only button on the unit, and the last measurement is displayed. This unit has only one measurement stored in memory. The A&D UA-774 has two start buttons, one green and one orange, and they can be used by two separate users so that each person's results can be stored separately in memory. To view past results, each user presses and holds the start button and the last measurement taken with that start button is displayed for 2 seconds, followed by the average of all the previous measurements for 2 seconds, followed by all the past measurements sequentially for 2 seconds each. Although there are no accessibility barriers related to pressing the correct buttons to perform these memory-related tasks, none of these HBPMs have the necessary speech output to accommodate blind and severely visually impaired users. Neither of the monitors with speech output has memory, a useful monitor feature for both patient and physician.

Controls

Table 2 shows the physical attributes of HBPM interface controls. The Microlife monitor has only one control button used for starting the blood pressure monitoring process and for accessing memory. The four A&D monitors without speech output have a start button and a separate memory button. The Omron HEM-757-E has three control buttons: power, start, and memory. The A&D 767T has a start button, a volume slider, and a switch for setting initial cuff inflation pressure. The other monitor with speech, the MaxiAids Reizen, has four controls: a power button, a set button, a replay button, and a volume slider. The Omron HEM-705CP has five buttons: power, start, memory, and two additional buttons for setting the time and date. Overall, the controls were found to be easy to tactually identify and operate and are not an accessibility issue for blind or visually impaired HBPM users.

Table 2. Physical Attributes of Control Buttons

Blood pressure monitor	Omron		Microlife	A&D Medical					MaxiAids
	HEM-705CP	HEM-757-E	BP-3BT0-A	UA-779	UA-767PV	UA-774	UA-787	UA-767T	Reizen
Number of buttons	5	3	1	2	2	2	2	3	4
Button design	Three convex buttons, 2 flat; raised borders around all 5 buttons; 1 inset, others are flush with the border	Two convex buttons, 1 concave; raised borders on all 3 buttons	One large button flush with the curving panel	Both buttons part of panel with raised domes for tactile identification	Two inset convex buttons, with a raised border	Two inset convex buttons, with a raised border	One small inset, convex button, 1 large half-moon button with a ridge along the curve	One inset, convex button, 2 sliders	Three flat buttons slightly inset, 1 slider
Texture	Buttons are slightly rough with a smooth panel	Opposite texture for buttons and surrounding casing	Dimpled button adds texture to differentiate from panel	Buttons and panel all smooth	Buttons and panel all smooth	Buttons are slightly rough with a smooth panel	Buttons and panel all smooth	Buttons and panel all smooth	Buttons and panel all smooth

Regarding the physical design of the control interfaces, all of the monitors except one employ one or more techniques for making the control buttons tactually discernible, such as raised borders around the buttons, concave and convex shapes, raised domes on the buttons, or buttons that protrude from the panel. The only monitor that does not use one of those techniques uses a dimpled texture on the button to differentiate it from the panel. Three of the other monitors also use texture to further differentiate the buttons from the panels of the units. All of the monitors also use contrasting color to visually differentiate buttons from one another and from the panel of the units. The A&D UA-774 also has borders around its buttons that light up when the unit is on, providing further visual cues to button location. The physical controls on these monitors pose no significant barrier to easy operation for blind or visually impaired users, but an accessible manual would be needed to understand the function of the controls.

Speech Output

For blind users, speech output is the only practical way for an HBPM to convey test results and other information presented on the display screen. As stated earlier, only two monitors with speech output, the A&D Medical UA-767T and the MaxiAids Reizen, are available on the U.S. market and have FDA approval. Both of these units use a recorded human voice to speak the blood pressure and pulse measurements, and both feature a volume-control slider and headphone jack for privacy. The UA-767T uses a high-quality, easy-to-understand recorded human voice. However, it is more difficult to understand the high-pitched voice on the MaxiAids Reizen, but with minimal practice, it is easy to get accustomed to and understand. Although both of the speech-output monitors speak the value of the blood pressure and pulse readings, only the UA-767T speaks an error message when the unit malfunctions, and neither unit vocally alerts users of a low battery. Additionally, as stated earlier, both of these units require the user to manually set the minimum necessary cuff inflation volume. This task can be done nonvisually on the UA-767T because users set the inflation volume with a tactilely discernible switch that clicks into four distinct positions that correspond to the four available inflation volumes. However, this task is not accessible to blind users on the MaxiAids Reizen because users must press a series of buttons until the desired inflation volume is shown on the display screen, and that information is not spoken.

Displays

Table 3 shows the attributes of HBPM displays. The size of the display area is similar on eight of the monitors, ranging from 2.67 to 3.86 square inches, but the display is much larger on the A&D Medical UA-787, which measures 5.97 square inches. All the monitors feature very large font sizes for displaying blood pressure results and error messages, ranging from 172 to 226 minutes of arc (between 0.60 and 0.79 inches). The monitors also employ very large font sizes (small spatial frequencies) for the display of pulse rate measurements, ranging from 106 to 201 minutes of arc (between 0.37 and 0.70 inches). All of the HBPMs display both blood pressure and pulse rate results simultaneously, except the MaxiAids Riezen, which alternates the blood pressure and pulse results, showing blood pressure for 3.7 seconds and pulse for 2.2 seconds. This can be problematic for visually impaired persons because of the extra time needed to fixate and focus on thedisplay. Michelson contrast measurements range from 0.55 on the MaxiAids Reizen to 0.75 on the Omron HEM-757E monitor. The dominant spatial frequencies on blood pressure output range from 0.5 cycles per degree on the UA-787 to 0.7 cycles per degree on the UA-767PV and UA-774. Pulse rate spatial frequencies range from 0.6 cycles per degree on the MaxiAids Reizen to 1.1 cycles per degree on the HEM-705CP.

Table 3. Attributes of HBPM Displays

Blood pressure monitor	Omron		Microlife	A&D Medical					MaxiAids
	HEM-705CP	HEM-757-E	BP-3BT0-A	UA-779	UA-767PV	UA-774	UA-787	UA-767T	Reizen
Display area (in.^{2})	3.60	3.86	3.72	2.88	3.13	3.13	5.97	2.67	3.49
BP font size (min of arc)[a]	180	215	186	175	172	172	226	180	201
Pulse font size (min of arc)[a]	106	123	143	112	109	109	143	112	201
BP contrast[b]	0.67	0.75	0.72	0.60	0.66	0.65	0.63	0.56	0.55
Standard deviation (N = 8)	0.02	0.02	0.04	0.02	0.02	0.03	0.03	0.02	0.03
BP spatial frequency (line pairs/degree)									
BP font size	0.7	0.6	0.6	0.7	0.7	0.7	0.5	0.7	0.6
Pulse font size	1.1	1.0	0.8	1.1	1.1	1.1	0.8	1.1	0.6

[a] Measured using a 12-in. viewing distance.

[b] Michelson contrast, calculated as follows: $C_m = (L_{max} - L_{min})/(L_{max} + L_{min})$ under isotropic illumination (100 cd/m^2) via an integrating sphere.

Operational Setup

Task analyses revealed that the HBPM cuff must be properly positioned on the upper arm, a task that involves three steps. First, the user must slide his or her arm into the cuff until it is around the upper arm between the elbow and the shoulder. Next, the user lines up the flexible tube connecting the cuff to the main unit along the brachial artery, which runs down the inside of the forearm. This is accomplished by running the tube down the forearm and aligning it with the index finger. The final step is to secure the Velcro flap to hold the cuff in place. Properly placing the cuff is not a particularly difficult task and poses no substantial challenges to blind users. The hard, molded cuff that comes with the A&D Medical UA-787 monitor is easier to properly place on the arm, making it easier to align the tube along the brachial artery.

After the cuff is properly positioned, starting the process to test blood pressure and pulse is very easy. On most units, the user simply presses the start button and the unit begins inflating the cuff and the results are soon displayed. The two Omron monitors require the user to first press the power button to turn the unit on before pressing the start button. Because the controls on all the units are easy to discern tactually and visually, this process poses no significant barriers for blind or visually impaired users. However, an accessible manual is still required so that blind or visually impaired users can learn the function of each button and become familiar with the entire measurement process, including cuff placement.

Battery Replacement

All the monitors use AA batteries, which are easy to identify tactilely. The battery compartment doors can be located via tactile markings on all the units. The standard AA battery replacement technique of placing the negative or flat end of the battery toward the spring can be used in all the devices except the MaxiAids Reizen. It is not possible to determine the proper battery orientation on the Reizen non-visually because there is no tactile differentiation between the various battery positions in the battery compartment and the manual does not describe a practical procedure for positioning the positive and negative ends of each battery.

Manuals

Electronic versions of the manuals were available for all of the monitors, but only the manual for the MaxiAids Reizen, a file in Microsoft Word format, was accessible to blind computer users. The electronic files available with all the other manuals were created as PDF files, and although they are accessible to visually impaired people using screen magnification software, they were not designed in the proper manner to be accessible to blind people using screen reading software. Large-print manuals accommodating many visually impaired users are available with all of the A&D monitors, and an accessible manual recorded on audiocassette was also available for the A&D UA-767T, but no Braille manuals were available for any of the HBPMs.

Results of Interviews

Table 4 shows the results of telephone interviews with legally blind persons who monitor their blood pressure at home. Of the ten adults who were interviewed, four had type 1 diabetes and six had type 2 diabetes. Nine reported being hypertensive and one reported being hypotensive. Six self-reported that their legal blindness was due to diabetic retinopathy, and the remaining three reported etiologies of cataracts, astigmatism, and retinopathy due to premature birth.

Five of the ten legally blind persons interviewed were functionally blind (unable to read print material with a magnification aid) and all five used an HBPM. The reasons they gave for using the HBPM included doctor recommendation ($N = 3$), general concern about blood pressure, and concern about variable measurements.

Two of the functionally blind persons used an HBPM model with speech output (A&D UA-767T). When asked what they liked most about their HBPM, both stated speech output. Additionally, one mentioned the pulse measurement function and the other mentioned ease of use. However, one user of the A&D 767T (Participant #3) stated that the cuff was difficult to position properly. Furthermore, in response to the question about suggested HBPM improvements, the user had three recommendations: improve portability, clearer and more accessible operating instructions, and addition of a feature to automatically ensure proper cuff inflation. One user of the UA-767T (Participant #10) felt the HBPM was too expensive.

The three functionally blind persons who did not use an HBPM with speech output required assistance from a sighted person to read the blood pressure and pulse results from their HBPM display screens. They found the HBPMs easy to use, but in response to the question about suggested HBPM design improvements, they each said speech output. Participant #7, who used the Omron HEM-711AC, also suggested adding a molded cuff as well as a memory function. The Omron HEM-711AC does in fact already have memory capability, but the user was unaware of this fact because the manual is not accessible. These three functionally blind persons mentioned that the most valued aspects of their HBPMs were convenience, perceived accuracy, ease of use, peace of mind, and portability.

Table 4. Interviews of Legally Blind Persons Who Monitor Their Blood Pressure at Home

Participant	Level of visual function[a]	Gender/ age	Diabetes type 1 or 2/years diabetic	Hypertension or hypotension/ years	BPM used	Reason for home monitoring	Frequency of use	How test results are read	Ease of use	Most valued aspect of HBPM	Suggested HBPM improvement(s)
P1	VI	F/84	Type 2/21	Hypertension/10	A&D 767	Doctor recommendation	Twice weekly	Sighted assistance	Easy	Easy to use	Voice output
P2	VI	F/56	Type 2/5	Hypertension/35	Sphygmomanometer	Felt that blood pressure meds were not working	Once weekly	Magnifier	Easy	Peace of mind	Include built-in blood glucose monitor
P3	B	F/54	Type 2/7	Hypertension/6	A&D 767T	Concerns about white coat syndrome	Daily	Voice output	Difficult cuff assembly	Voice output and pulse reading	Improve portablility, clearer instructions, automatically sets cuff inflation volume
P4	VI	F/63	Type 2/20	Hypertension/30	A&D 767	Noticed changes in blood pressure when under stress	Twice weekly	Visually at close range	Easy	Large display font	Voice output and large-print manual
P5	VI	F/72	Type 2/40	Hypertension/8	Sphygmomanometer	Noticed changes in blood pressure	Twice weekly	Magnifier	Easy	Peace of mind	Voice output
P6	B	M/35	Type 1/27	Hypertension/15	Omron HEM-712C	Doctor recommendation	Weekly	Sighted assistance	Easy	Convenience and accuracy	Voice output
P7	B	M/54	Type 1/44	Hypertension/4	Omron HEM-711AC	Doctor recommendation	Daily	Sighted assistance	Difficult cuff assembly	Ease of use and accuracy	Voice output, molded cuff, memory
P8	VI	F/48	Type 2/20	Hypertension/8	Microlife BP-3AA1-2	Concerns about hypertension	Three times daily	Visually at close range	Easy	Accuracy	Voice output
P9	B	F/46	Type 1/32	Hypotension/12	Omron HEM-739	Concerns about hypotension	Three times weekly	Sighted assistance	Easy	Peace of mind and portability	Voice output
P10	B	F/46	Type 1/40	Hypertension/15	A&D 767T	Doctor recommendation	Three times weekly	Voice output	Easy	Voice output and ease of use	Lower cost

[a]VI denotes able to read print material with a magnification aid, B denotes unable to read print material with a magnification aid.

Five of the ten legally blind persons interviewed were visually impaired (able to read print material with a magnification aid). Three used an HBPM and two used mercury sphygmomanometers. The reasons given for monitoring their blood pressure included changes in blood pressure ($N = 2$), doctor recommendation, concern about effectiveness of blood pressure medication, and general concern about hypertension.

None of the visually impaired persons interviewed had a monitor with speech output. One used assistance from a sighted person to read blood pressure results, two read the display with a magnification aid, and two read the display without a magnification aid at close range. Four found their monitor easy to use, but one found it difficult to properly position the cuff. In response to the question about suggested improvements, four suggested speech output. One person also suggested a large-print operating manual. The aspects of their monitors that they valued most were large display fonts and accuracy.

Among all ten of the interviewees, the two who used monitors with speech output were the only interviewees aware that HBPMs with speech output are available on the market. The six who used HBPMs without speech output simply went to their local drug store and picked one off the shelf. Of the two who used monitors with speech output, one had read about her monitor in an article in a technology magazine targeted toward blind and visually impaired people. The other person contacted various assistive technology vendors asking them if they offered any HBPMs with speech output and found one vendor that did. The two who used mercury sphygmomanometers were given the device by a relative in the health care field. No interviewees were given a recommendation by a doctor to purchase a monitor with speech output or to purchase any other specific monitor.

Conclusions

Of the target group of nine HBPMs, only two (A&D's UA-767T and MaxiAids' Reizen) had speech output. Although both of these units do provide speech output to convey blood pressure and pulse results, neither provides speech output to convey all the information that is displayed on the screen. Only the UA-767T speaks error messages that appear on screen, and neither voices a low battery warning. Additionally, the Reizen does not have the speech output necessary for setting the initial cuff inflation volume. Battery replacement in the Reizen is not fully accessible, but could be if instructions were designed to orient the blind or visually impaired user. Only the two HBPMs with speech output also lack a feature for automatically setting cuff inflation volume and the ability to store memory, highlighting the fact that blind and visually impaired persons are not getting access to equivalent full-featured HBPMs available to sighted persons. This is not surprising considering that so few HBPMs on the market offer speech output.

The characterization of Michelson contrast for HBPM displays is an objective of this study because it is considered by some to be the best and most complete single-metric description of the ability of a display to exhibit information.[18,20] More generally, the Michelson contrast for a sinusoidal luminance pattern as a function of the spatial frequency of the pattern is referred to as the modulation transfer function (MTF) of the system. As noted earlier, a smaller font producing more detail on a smaller spatial scale will possess a higher dominant spatial frequency.

While the fonts on the displays of the HBPMs were large and adequate, the measures of the displays' Michelson contrast and spatial frequency compiled in this study cannot be benchmarked at this time because no visual display design standards yet exist. Next steps toward the goal of developing such standards include conducting a clinical study to investigate a correlation between single digit character recognition and an objective measure of the image quality of a small visual display. We will use Barten's square-root integral (SQRI) image quality metric, which is computed from a weighted combination of the physical parameters of the image, as characterized by the MTF of the display, and a psychophysical parameter of the human visual system, as characterized by the subject's contrast sensitivity function (CSF).[21] The SQRI has been demonstrated to linearly correlate to subjective image quality over a wide range of image qualities. A successful correlation to single digit recognition (presented at the same luminance, field size, and low-frequency Michelson contrast as for the HBPM characters) and the SQRI should allow one to predict if a display will be appropriate for a visually impaired person with a given CSF.

Physical controls were found to be easy to identify, and operating procedures were found to be relatively simple on all of the HBPMs. Only the A&D Medical HBPMs are available with large-print manuals to accommodate visually impaired users. No Braille manuals are available for any monitors, and only the MaxiAids Reizen is available with an accessible electronic version of its manual to accommodate blind users.

Interviews with blind and visually impaired people who monitor their blood pressure at home revealed that speech output is a highly valued feature for both blind and visually impaired users. However, persons who were not using HBPMs with speech output were unaware of the fact that HBPMs with speech output are available. Similarly, interviewees who were part of a blood glucose monitor study in 2002 were unaware of monitors on the market with speech output.[22] Additionally, an informal survey of Certified Diabetes Educators revealed that none of the educators surveyed were aware of HBPMs with speech output.[22] The importance of an accessible operating manual that provides clear and easy to follow instructions was also mentioned often.

In summary, HBPMs are easy-to-use devices, especially when compared to blood glucose monitors (BGMs) and insulin pumps (IPs).[23,24] Additionally, unlike BGMs and IPs, HBPMs do not present accessibility barriers that are difficult to surmount, either technically or operationally. Two HBPMs with voice output were found to have a significant degree of accessibility, but there is definitely room for improvement. Furthermore, they were not found to offer as many features as those HBPMs that were less accessible. Recommendations for advancing the state of accessibility of HBPMs include the following:

1. Voice output of all display information.
2. The development of visual display standards that specify a minimally acceptable level of Michelson contrast.
3. Feature sets that include automatic setting of cuff inflation volume and memory storage capability.
4. Operational manuals that are accessible to blind and visually impaired persons.
5. A higher degree of awareness of accessible HBPMs among health care professionals so that the information can be passed to blind and visually impaired patients.

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