CS6750 Project (Summer 2021)

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1 INTRODUCTION

According to the recent statistical data released by the World Health Organization, hypertension, or elevated blood pressure, impacts an estimated 1.13 billion people worldwide (World Health Organization, 2021). Hypertension is one of the major causes of premature deaths around the world, as it can significantly increase the risk of heart, brain, kidney, and other detrimental health conditions. Noting that, fewer than 1 in 5 people with hypertension have it under control, as most people with it have no signs or symptoms, even if their blood pressure readings are at dangerously high levels. Due to this, hypertension is often called a "silent killer", where it can lead to heart attacks, heart failures, strokes, kidney failure, and even sudden death (Mayo Clinic, 2021). On that note, accurate blood pressure readings are imperative in administering correction medical treatment, as it can result in a misdiagnosis that may: (1) leave hypertension untreated, or (2) lead to unnecessary treatment, causing hypotension, or low blood pressure, that can sometimes be fatal (Beckerman, 2021).

In terms of measuring blood pressure, many patients, especially those with diagnosed cases of hypertension, are often instructed by their medical providers to perform self-measurement in their homes using *automatic sphygmomanometers* based on the *oscillometric technique* (Ogedegbe & Pickering, 2010). While there are notable benefits of at-home monitoring such as limiting the "white coat effect" (Ogedegbe & Pickering, 2010), or elevated blood pressure caused by the anxiety of talking to a physician, there are some significant factors that need to be addressed. For one, there are seven different "cuff sizes" recommended based on the individuals' age and arm circumference (American Heart Association, 2021), where an incorrect cuff size usage can often lead to overestimation of blood pressure. Additionally, even if the correct cuff sizes are utilized, an incorrect cuff tightness can result in incorrect readings, where over-tightness causes overestimation, and under-tightness causes underestimation.

In this report, the currently existing physical interface of the *automatic sphygmomanometer cuff* was analyzed to derive a redesigned interface through *needfindings*, *heuristic evaluations*, and *prototyping*. And once a redesigned interface prototype was generated, the new interface went go through: (1) a process of justification by describing how it addresses the criticisms initially identified, and (2) derivation of an evaluation plan to test the new interface through a qualitative or empirical process for validity.

2 INITIAL NEEDFINDING

In the *initial needfinding*, the physical interface of the *sphygmomanometer cuff* was analyzed for: (1) its existing weaknesses, (2) what the interface does not presently do well, and (3) any lacking features that the interface should have. Noting that the two needfinding methods utilized were: (1) *reading existing product reviews*, (2) *evaluating existing interfaces*, and (3) *interviews*.

2.1 Needfinding 1 – Reading existing product reviews

The *reading existing product reviews* method was utilized to gather information specific to: (1) *"who are the users"* – what are the levels of expertise of the current users, and (2) *"what do they need"* – what are the physical objects and information the users need to accurately measure their blood pressure in detail. This *needfinding* consisted of the following steps: (1) Identifying the top at-home *automatic sphygmomanometers* on Amazon based on the number of sales. (2) Collecting 100 most recent negative reviews from the product identified. (3) Analyzing the reviews collected for the level of expertise of the users. And lastly, (4) Analyzing the reviews collected for what the users need in terms of its existing weaknesses, what it does not do well, and what features it is currently lacking.

The top at-home *automatic sphygmomanometer* on Amazon based on the number of sales at the time of this study was *"OMRON Bronze Blood Pressure Monitor"* (*Figure 1*), which included a cuff that was advertised to fit all large and standard adult arms from 9" to 17" in circumference (OMRON, 2019). Once this product was identified, "all critical" reviews were sorted by "most recent", and the first 100 reviews from the sorted list were selected for analysis. The summary of the critical review analysis is as follows: First, the level of expertise of the users was extremely diverse, with the users being either doctors, nurses, dentists, caregivers, or patients themselves. Some of the purchasers were physicians that provided the device to their patients specifically for at-home monitoring of their hypertension. Second, out of the 100 reviews analyzed, 86% of the reviews indicated issues with inaccurate readings, typically indicating that their device was "higher than in-office readings" provided by their physicians on site. Third, 53% of the reviews reported issues with the cuff itself, stating that it either "over-inflated" or "underinflated" frequently, while some indicating that the cuff was either "too wide" or "too tight" to fit their arm. And lastly, the difference in the systolic pressure readings reported by the users ranged from 10 to 40 mmHg. This finding is extremely significant as someone with a normal systolic blood pressure of 120 mmHg can be misdiagnosed as having hypertension stage 1 (130 - 139 mmHg) or stage 2 (140+ mmHg), given the error ranges being reported by the device reviews.

Figure 1 *— OMRON Bronze Blood Pressure Monitor*. Source: Amazon.

The main takeaway from *reading existing product reviews* was that while the expertise in the user base of the *automatic sphygmomanometer cuffs* was ranging from professionally trained medical providers to patients themselves, there were a significant number of concerns being raised regarding the inaccurate readings. Notably, a large percentage of the negative reviews also raised concerns about the sizing, fit, and inflation of the cuff itself, often attributing the inaccurate readings to the issues with the cuff. On that note, while the device itself is advertised with a specification for the cuff sizing, the users reporting issues with fitment indicate that the users *need* assistance with both: (1) identifying the correct cuff sizes for their arm, and (2) identifying the correct arm placement of the cuff. The insights gathered from this *needfinding* were used to: (1) identify alternate existing interfaces to be evaluated in the next *needfinding* plan (*Section 2.2*), and (2) derive questions for the subsequent *needfinding* plan of *interviews* (*Section 2.3*).

2.2 Needfinding 2 – Evaluation of existing interfaces

The *evaluation of existing interfaces* method was utilized to gather information specific to: (1) *"what are their tasks"* – what are they doing physically, cognitively, and socially when using the current interface, and (2) *"what are their subtasks"* – how do they accomplish the steps in getting their blood pressure readings. This *needfinding* consisted of the following processes: (1) Obtaining competing at-home *automatic sphygmomanometer* to the interface identified above (*Section 2.1*). (2) Deriving a list of instructions for the participants to follow. (3) Placing the competing interface in front of participants. (4) Asking the participants to *think aloud* about what they are looking at, how they are interpreting the instructions, and what they are thinking if they happen to get stuck. And lastly, (5) using the *notetaking* approach to gather *qualitative data* from the participants.

The competing interface that was utilized for the *evaluation of existing interface* method was the *"Withings BPM Connect – Wi-Fi Smart Blood Pressure Monitor"* (*Figure 2*). This FDA-approved device was selected for evaluation as it was being marketed as a "highly accurate" and "convenient" device that makes the process of blood pressure monitoring "simple and understandable" (Withings, 2019), while also integrating the reader into the cuff itself. As a note, the cuff for this device was also advertised to fit all large and standard adult arms from 9" to 17" in circumference. For the evaluation, the device was placed in front of the participants and was designed to be: (1) live demonstrations, (2) synchronous, (3) looking at *one interface*, (4) using the think-aloud protocol, and lastly (5) evaluating single individuals at a time (Joyner, 2021l & 2021n). The *qualitative data* was gathered from a total of four participants who were currently utilizing a traditional *automatic sphygmomanometer* device like the one mentioned above (*Section 2.1*), and the results were evaluated to derive the main takeaways.

Figure 2 *— Withings BPM Connect – Wi-Fi Smart Blood Pressure Monitor.*
Source: Amazon.

The main takeaways from *evaluating existing user interface* of the *Withings Blood Pressure Monitor* were as follows: First, the device was easier to understand in terms of cuff placement in general. This wasn't due to any automated system that assisted the users in the placement, but solely due to the nature of the device design itself. The cuff was stiffer in comparison to the traditional *automatic sphygmomanometers* due to the reader placement, therefore the participants were automatically able to identify the logical and correct placement of the cuff, which was directly above the elbow joints surrounding their biceps. Additionally, because the cuff width was constantly for the range of supported arm circumferences, there were no notable variations in the placement across all four participants. Second, all the participants were resoundingly positive about the lack of "tubing" that is present in traditional *automatic sphygmomanometers* from the cuff to the reader itself. This was particularly insightful as two of the participants noted that they often had difficulty getting their traditional cuffs placed properly due to the tubing interfering with their setup process. The insights gathered from this *needfinding* were used to derive additional questions for the *interviews* (*Section 2.3*), specifically leveraging the *tasks* and *subtasks* identified in utilizing *automatic sphygmomanometers* in the current *needfinding* step, and to design the new interface (*Section 4*).

2.3 Needfinding 3 – Interviews

The *interview* method (Joyner, 2021j) was utilized to gather more "targeted" data specific to: (1) *"what are their goals"* – what are they trying to accomplish, and (2) *"what do they need"* – what are the additional physical objects, information, and collaborator they need right now to accurately measure their blood pressure. This *needfinding* consisted of the following processes: (1) Deriving a list of questions to ask for the interviews specific to identifying what the users need to accomplish their goals. (2) Ensuring that most of the conversation occurred on the interviewee's side to minimize biases. And lastly, (3) Structuring the interviews with distinct portions for organized data gathering.

While the exact list of questions slightly differed for each session, the interviews were structured to ensure that they: (1) focused on the six W's of *who*, *what*, *when*, *where*, and *how*, (2) were being aware of the biases that may predispose the participants to certain views, (3) listened to the participant by ensuring that they were doing the vast majority of the talking, and (4) were organized to have an introduction phase to build trust, main phase, and summary at the end to ensure that the participants understood the purpose of the questions (Joyner, 2021?). The *interviews* consisted of a total of five participants who were currently utilizing a traditional *automatic sphygmomanometer* device like one mentioned above (*Section 2.1*), and the results were evaluated to derive the main takeaways.

The main takeaways from the *interviews* were that: First, while the duration in which the participant has been self-monitoring their blood pressure varied, ranging from under 6 months to over 10 years, all participants experienced five or more instances of inaccurate blood pressure readings from their at-home *automatic sphygmomanometer* in comparison to the in-office readings performed by their physicians and their associated medical staff. Noting that, the reasons behind the inaccurate readings were associated with either: (1) incorrect size cuff being utilized, or (2) incorrect usage of the cuff itself. Second, four of the five participants noted "difficulties" correctly placing and utilizing their blood pressure cuffs. This was generally due to the rather complicated process of placing, tightening, and connecting the cuff tubing to the reader using only one hand, as the arm used for measurement was limited in its movement. And lastly, when prompted for any additional insights, three of the participants expressed the lack of "feedback" from the devices themselves in terms of letting them know whether the sizing, tightness and placement of the cuff were correct. This was particularly insightful as neither the currently existing *automatic sphygmomanometers* described above (*Section 2.1*) or the alternative devices used for *evaluation* above (*Section 2.2*) provided feedback that let the users know whether the sizing, tightness and placement of the cuff were correct. Noting that, a feature that can automatically let the users know whether their various *subtasks* in setting up their *automatic sphygmomanometer cuffs* were conducted correctly would provide significant improvements to the existing interface that addresses the various needs identified in the *needfinding* steps. The insights gathered from this *needfinding* were used to derive ideas for the redesigned interface (*Section 4*).

3 HEURISTIC EVALUATION

The *automatic sphygmomanometer cuff* interfaces as it currently exists has several rooms for improvement as shown in the *needfinding* exercises performed above (*Section 2*). On that note, there are many notable aspects of the existing interface that also works well in terms of a heuristic perspective. In this section, *heuristic* *evaluations* will be conducted on the existing interface to answer the following questions: (1) What works well? (2) What makes it work well (3) What doesn't work well? And (4) Why doesn't it work well.

3.1 What works well and why

The at-home *automatic sphygmomanometer cuffs*, such as the included with "*OMRON Bronze Blood Pressure Monitor*" described above (*Section 2.1*), provides an interface that allows users with diverse levels of expertise to monitor their blood pressure effectively in the context of their choosing. Noting that, in comparison to the alternative method of getting measurements taken at a medical providers office, there are various *design principles* and *heuristics* of (1) *Discoverability*, (2) *Simplicity*, (3) *Mapping*, (4) *Consistency*, and (5) *Affordances* that makes some portions of the interface work well. Following are the descriptions of each of the identified *design principles* and *heuristics*, and how they relate to making the interface work well:

First, the *discoverability* design principle asks the question of "is it possible to figure out what actions are possible and where and how to perform them?" (Norman, 2013). In other words, the interface should be designed so that when the user doesn't know what to do, they should be able to figure out what to do. Noting that, the interface of the *OMRON Bronze Blood Pressure Monitor cuff* provides easy-to-understand visual instructions that allow the users to identify what needs to be done directly on the interface (*Figure 3*).

Figure 3 — OMRON Blood Pressure Monitor Cuff Interface. Source: Amazon.

This allows the user to figure out what to do based on pictographic and textual information without referencing a separate user's manual for relevant usage instructions.

Second, the *simplicity* design principle states that “the design should make simple, common tasks easy, communicating clearly and simply in the user’s language, and providing good shortcuts” (Constantine & Lockwood, 2002). Noting that, the pictographic representation supported by both imperial and metric measurements provides a simple interface that not only makes the task of placing the cuff easier, but also communicates the recommended placement of the cuff in measurements that the user can understand. Additionally, the single button start/stop functionality makes the common task of starting or stopping the blood pressure measurement process simple and easy to perform.

Third, the *mapping* design principle states that “the system should speak the user’s language, with words, phrases, and concepts familiar to the user, rather than system-oriented terms” (Nielson, 1994). Noting that, like the *simplicity* design principle (Joyner, 2021b), the current interface maps the actions that the user should take in a concept familiar to the user by showing exactly how and where the cuff should be placed. The pictographic representation not only shows the orientation of the cuff and tubing but clearly demonstrates which arm and where the cuff should be placed, allowing the user to map the interface to their own actions.

Fourth, the *consistency* design principle states that “The design should reuse internal and external components and behaviors, maintaining consistency with purpose rather than merely arbitrary consistency, thus reducing the need for users to rethink and remember” (Constantine & Lockwood, 2002). Noting that, the principle of consistency is shown in the existing *automatic sphygmomanometer cuff* interface as it not only follows the look and feel of the general industry standard of *automatic sphygmomanometer cuffs*, but the usage, placement, and functionality is consistent with the ones the users would’ve come across in their medical provider’s offices. This allows the user to focus on the task at hand while minimizing the need to learn the interface independently.

Lastly, the *affordances* design principle states that “An affordance is a relationship between the properties of an object and the capabilities of the agent that determine just how the object could be possibly used” (Norman, 2013). This principle is reflected in the existing interface as the interface design itself tells the user how to use it (Joyner, 2021c). In more detail, the adjustable cuff comes with a pictographic *signifier* that aids in matching the *perceived affordance* with the *actual* *affordance* of the cuff. While there can be confusion in which direction the tubing should be facing when putting on the cuff, the pictographic *signifier* provides necessary information that allows the user to determine how the cuff is used.

3.2 What doesn't work well and why

While there are various *design principles* and *heuristics* noted above (*Section 3.1*) that support why the interface of the *automatic sphygmomanometer cuff* works well, as shown in the *needfindings* above (*Section 2*), there are various factors why the interface does not work well. These factors can be attributed to the lack of the following *design principles* and *heuristics*: (1) *Perceptibility*, (2) *Flexibility*, (3) *Equity*, (4) *Ease and Comfort*, and (5) *Feedback*.

First, the *perceptibility* design principle states that "the design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities" (Mace, 1997). Noting that, the current cuff interface goes through the process of inflating and deflating but does not allow the user to perceive what stage of the inflation and deflation process it is currently, and each time the user tightens the cuff and turns on the *sphygmomanometer*, the duration, and the amount in which the cuff inflates differs. Although there are logical reasons why these variances in the duration and amount of inflation exist (i.e., ensuring adequate pressure before measurement based on the *oscillometric technique* starts), no information is provided for the remaining time, current, and desired pressure. Additionally, the current design does not account for differences in the user's sensory abilities (Joyner, 2021d). While the current state of the cuff can be determined approximately based on the pressure applied to the user's arm, this perception can vary heavily based on the user's sensitivity to physical pressures.

Second, the *flexibility* design principle states that "the design accommodates a wide range of individual preferences and abilities" (Mace, 1997). Noting that, the current interface design accommodates only a single usage case, without any flexibility based on the user's preference or abilities. Based on the inherent design and the pictographic information (*Figure 3*), the current interface assumes that: (1) the user has both of their limbs and hands, (2) the cuff always will be used on their left arm, (3) the user is right-handed, and (4) the user knows exactly how much tightness to apply. This goes against the principle of *flexibility* (Joyner, 2021e) as it does not accommodate some users with disabilities or preferences in selecting the arm and tightness that is comfortable to their circumstances.

Third, the *equity* design principle states that "the design is useful and marketable to people with diverse abilities" (Mace, 1997). Specifically, equity is largely about helping all users have the same user experience regardless of their abilities. Noting that, complementary to *flexibility* above, the current interface does not account for the difference in the user's abilities, whether that is physical, mental, or contextual. As an example, if a user is paralyzed on their right arm, what are the means for them to be able to tighten the cuff on the left arm? Or if the user has limited mobility in both of their hands, how would they tighten the cuff correctly? Based on these factors, the current design does not follow the design principles of *equity* in an effective manner.

Fourth, the *ease* design principle states that "the design can be used effectively and comfortably and with a minimum of fatigue", and the *comfort* design principle states that "Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility". Noting that, the current interface neither allows the users to utilize the interface effectively and comfortably, nor accounts for differences in the user's body size, posture, or mobility. As an example, as shown in the *needfinding* of *interviews* above (*Section 2.3*), some of the users experienced "difficulties" correctly placing and utilizing their blood pressure cuffs. Some of these difficulties were attributed to the fact that the interface assumed that the users had adequate arm circumference, and the associated mobility to be able to tighten the cuff around their arm using only one hand. This goes against the principle of *ease* and *comfort* as the current interface does not accommodate the various abilities of the user in using the interface in an easy and comfortable manner (Joyner, 2021g).

Lastly, the *feedback* design principle states that "the design should keep users informed of actions or interpretations, changes of state or condition, and errors or exceptions … through clear, concise, and unambiguous language familiar to the users" (Constantine & Lockwood, 2002). Noting that, the *automatic sphygmomanometer cuff* interface itself does not keep the user informed of any actions, state changes, or errors. The duration and pressure of the cuff are ambiguous, and the inflation and deflation process is unclear as to how long it is supposed to take. Additionally, the cuff sometimes spontaneously re-inflates itself during the deflation phase, without relaying to the user why this is occurring. This goes against the principle of *feedback* as there is a clear lack of information relay to the user in terms of any actions, state changes, or errors (Joyner, 2021i) that might be critical for the user in understanding what and why something occurs.

4 INTERFACE REDESIGN

Based on the initial *needfindings* (*Section 2*) and the *heuristic evaluation* (*Section 3*) conducted above, the following *high-fidelity prototype* (Babich, 2017) was generated that represents the redesigned interface of an *automatic sphygmomanometer cuff*. Noting that, the overall redesigned interface will be described first, followed by a detailed description, functionality, and purpose of each sub-components.

4.1 Overall redesign overview

The redesigned interface consists of *six* main key components encased in a singular system that integrates the *automatic sphygmomanometer* with the *cuff* as a built-in mechanism. The *six* components are as follows: (1) *angled armrest*, (2) *blood pressure indicator*, (3) *start/stop button*, (4) *cuff pressure indicator*, (5) *self-inflating cuff*, and (6) *elbow contact sensor*. The overall redesigned interface with each of the components labeled is shown below (*Figure 4*) for visualization, with each component labels annotated by colored arrows for identifiability.

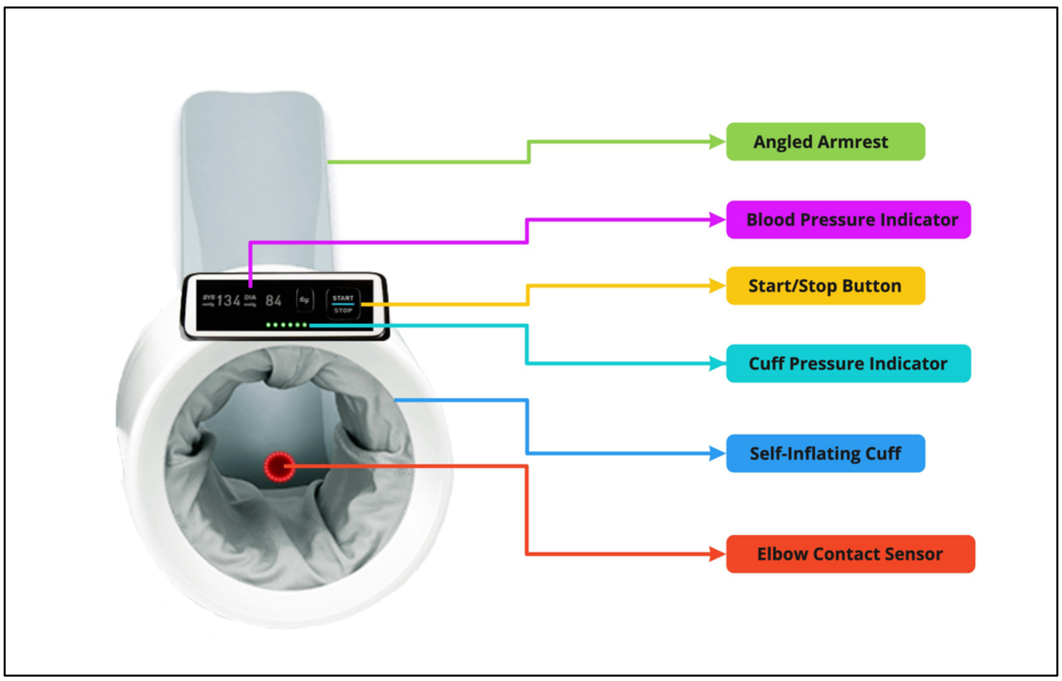

Figure 4 — Redesigned Automatic Sphygmomanometer Interface.

4.2 Subcomponent – Angled Arm Rest

The *angled armrest* component (*Figure 5*) consists of a concaved plastic panel that is used to rest the user's arm during the blood pressure measurement. This component connects to the *self-inflating cuff* component *(Section 4.5)* at a 45-degree angle, opposite to the side of the cuff where the user's arm is inserted. Additionally, this component is redesigned to be detachable from the *self-inflating cuff* component for ease of storage when the interface is not in use.

Figure 5 — Angled Arm Rest Component.

4.3 Subcomponent – Blood Pressure Indicator

The *blood pressure indicator* component (*Figure 6*) is part of the LED screen that displays the systolic and diastolic blood pressure measurements in the standard millimeters of mercury (mmHg) unit of measure. The measurements are calculated automatically and displayed during inflation, deflation, and completion, with completion showing the final readings based on the *oscillometric technique*.

Figure 6 — Blood Pressure Reading Component.

4.4 Subcomponent – Start/Stop Button

The *start/stop button* component (*Figure 7*) is part of the LED screen that the user interfaces with to start and stop the blood pressure measurement cycle process. The button is a *capacitive* touch interface, where the press is registered due to the change in the screen's electrical charge caused by the conductivity of the user's skin. Noting that, this interface registers button presses with minimal force. Note, additional start/stop functionality noted below (*Section 4.7*).

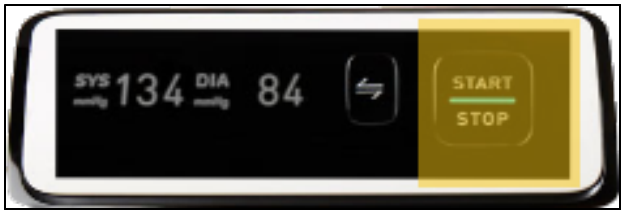

Figure 7 — Start/Stop Button Component.

4.5 Subcomponent – Cuff Pressure Indicator

The *cuff pressure indicator* component (*Figure 8*) is part of the LED screen that the user interfaces with to determine the status of the automated cuff tightening and inflation/deflation process. This indicator consists of six green LEDs that progressively turn on from left to right as the cuff reaches its optimal tightness and pressure. And once the optimal tightness and pressure are reached, the device plays an "optimal fit has been reached" audio message, letting the user know the status. Then, as the measurement is completed and the cuff deflates, the indicator LED progressively turns off from right to left until fully deflated, again followed by an audio message that states, "measurement complete".

Figure 8 — Cuff Pressure Indicator Component.

4.6 Subcomponent – Self-Inflating Cuff

The *self-inflating cuff* component (*Figure 9*) consists of a circular plastic tube that encases an inflatable membrane where the users insert their arms for oscillometric blood pressure measurement. The arm entry circumference of the cuff supports a large range of arm circumference sizes from *16* to *44 centimeters* (all adult sizes), which stays at the widest and deflated circumference before the *start/stop button* (*Section 4.4*) is pressed to initiate the blood pressure measuring process.

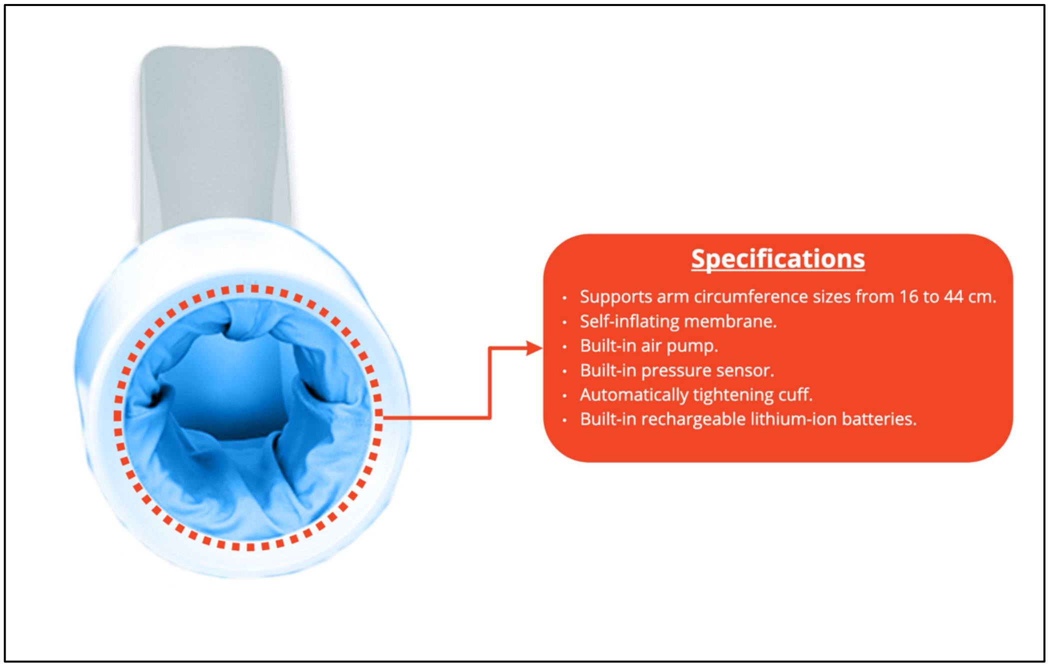

Figure 9 — Self-Inflating Cuff Component.

Additionally, the inflatable membrane cuff has a built-in automated pressure sensor that determines the optimal tightness of the cuff around the user's arm, then adjusts the cuff size for optimal fit as shown below (*Figure 10*). This mechanism works by using a belt drive system that incrementally squeezes or releases based on the user's arm circumference until optimal fit is reached.

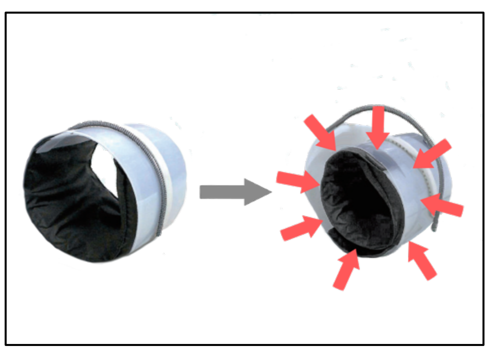

Figure 10 — Automatic Cuff Tightening Mechanism.

4.7 Subcomponent – Elbow Contact Sensor

The *elbow contact sensor* component (*Figure 11*) consists of a *capacitive sensor* that is used to check the presence and the proximity of the user's elbow to ensure proper positioning of the arm relative to the entire device (*Figure 4*). The *elbow contact sensor* is indicated by a series of LED bulbs that stays red until adequate proximity is reached, wherein which the LED color transitions from red to green, indicating proper arm placement. Additionally, once the adequate elbow contact is made and the indicator lights up green, the device automatically starts the measurement process proceeded by an auditory message of "starting measurement cycle".

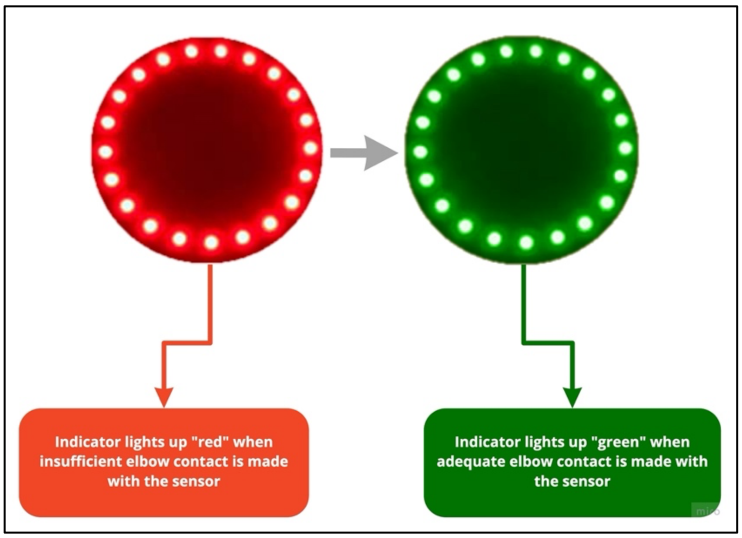

Figure 11 — Elbow Contact Sensor.

5 INTERFACE JUSTIFICATION (3 PAGES)

As noted above, while the original interface of the *automatic sphygmomanometer cuff* had some aspects of it that worked well (*Section 3.1*), there were various factors noted in the *needfinding* methods of *reading existing product reviews*, *evaluation of existing interfaces*, and *interviews* (*Section 2*), that exposed some of its shortcomings. And as a recap, these factors were attributed to the lack of the following *design principles* and *heuristics*: (1) *Perceptibility*, (2) *Flexibility*, (3) *Equity*, (4) *Ease and Comfort*, and (5) *Feedback* during the *heuristic evaluation* above (*Section 3.2*). Noting that, the interface was redesigned (*Section 4*) to not only address the criticisms gathered from the *needfinding* methods but also to improve the overall *simplicity* of the entire interface. In the following sections, the redesigned interface is analyzed specifically on: (1) Which positive elements from the original interface were preserved, (2) How the redesigned interface addresses each of the criticism raised, (3) Which *design principles* and *heuristics* are improved from the redesign, and lastly (4) Which *design principles* or *heuristics* was leveraged to further improve the interface further.

5.1 Positive elements preserved

One positive element that was preserved from the original interface in the redesign was the *simplicity* provided by the *start/stop button*. The *start/stop button* in the existing interface allowed the user to start or stop the blood pressure measurement process using a single press of the button (*Figure 1*). This element was preserved in the redesign as the single button was very effective in reducing the *cognitive load* of the user (Joyner, 2021a), by limiting the amount of information that the user needed to keep in mind during interface usage.

5.2 Addressing lack of *perceptibility*

The existing interface lacked the *design principle* of *perceptibility* as the *automatic sphygmomanometer cuff* went through a process of inflation and deflation without allowing the user to perceive what stage of the inflation and deflation process it was in (*Section 3.2*). Additionally, the existing interface also did not account for differences in the user's sensory abilities, wherein which the users could perceive the current stage of the inflation process using the pressure applied to their arm. Noting that, the *cuff pressure indicator* (*Section 4.5*) in the redesigned interface addresses these criticisms by relaying to the user the current stage of the inflation/deflation process. The gradually lit LEDs visually convey the current stage of the inflation/deflation, and the auditory messages of "optimal fit have been reached" and "measurement complete" convey to the user whether the pressurization or depressurization has been concluded. These changes in the redesigned interface improve the *design principle* of *perceptibility* by relaying the necessary information to the user throughout the process, while also accounting for differences in the user's sensory abilities both visually and auditorily.

5.3 Addressing lack of *flexibility*

The existing interface lacked the *design principle* of *flexibility* as it assumed that: (1) the user has both of their limbs and hands, (2) the cuff will always be used on their left arm, (3) the user is right-handed, and (4) the user knows exactly how much tightness to apply. This did not accommodate users with certain physical disabilities in a comfortable manner. Noting that, the *self-inflating cuff* (*Section 4.6*) of the redesigned interface addresses this criticism by not only providing an interface that can be used by either the left or right arm, but also automating the tightening aspect of the cuff by incorporating a sensor-based belt-drive mechanism. These changes greatly improve the *design principle* of *flexibility* by accounting for the physical abilities of a wide range of users.

5.4 Addressing lack of *equity*

The existing interface lacked the *design principle* of *equity* as it did not allow the same user experience regardless of their abilities. Notable in the example above (*Section 3.2*), the existing interface did not account for: (1) users missing one of their arms, (2) users that cannot get measurements on their left arm, (3) users who are left-handed, and (4) users without the knowledge of how tight the cuff should be. Noting that, as with *flexibility* above (*Section 5.2*), the *self-inflating cuff* (*Section 4.6*) of the redesigned interface addresses this criticism by not only providing an interface that can be used by either left or right arm but also automating the tightening aspect of the cuff by incorporating a sensor-based belt-drive mechanism. These changes greatly improve the *design principle* of *equity* (Joyner, 2021f) by providing an interface that helps all users have the same experience regardless of their physical or mental abilities.

5.5 Addressing lack of *ease and comfort*

The existing interface lacked the *design principle* of *ease and comfort* as it did not accommodate a wide enough range of user's body size, specifically their arm circumference, with some users noting that the cuff was either "too wide" or "too tight" to fit their arm (*Section 2.1*). Additionally, because the existing interface depended on the usage of two fully functional arms and hands, it did not account for users with limited mobility in their upper extremities. Noting that, the *self-inflating cuff* (*Section 4.6*) of the redesigned interface addresses these criticisms by eliminating the need for the user to tighten the cuff themselves. Also, the *elbow contact sensor* (*Section 4.7*) provides an automated insert and start functionality that automatically starts the blood pressure measuring process once the sensor conditions are met. This addresses these criticisms by allowing the blood pressure measurement to be conducted easily and comfortably without worrying about potential mobility issues associated with their other free arm and hand.

5.6 Addressing lack of *feedback*

The existing interface lacked the *design principle* of *feedback* as the *automatic sphygmomanometer cuff* interface itself does not keep the user informed of any actions, state changes, or errors. Noting that, the built-in *blood pressure indicator* (*Section 4.3*), the *cuff pressure indicator* (*Section 4.5*), and the *elbow contact sensor* (*Section 4.7*) significantly increases the *design principle* of *feedback* as these subcomponents of the redesigned interface collectively convey to the user of: (1) the automated actions that are taken by the device, (2) various state changes of the interface both visually and auditorily, and (3) errors such as reflation of the cuff in a visual manner using the *cuff pressure indicator*. Cohesively, these changes provide clear *feedback* to the user in terms of any actions, state changes, or errors that are critical to the operation and usage of the interface.

5.7 Further improvement

Noting the various lack in *design principles* and *heuristics* addressed in the redesigned interface (*Section 5.2 to 5.6*), a couple of additional *design principles* were leveraged to further improve the interface. First, the *design principle* of *simplicity* was further improved by providing various automated features in using the interface (*Section 4.6 & 4.7*), while also eliminating the various steps that the user had to perform prior to initiating the measurement (i.e., tightening the cuff, connecting the tube from the cuff to the reader). This assisted the interface to make common tasks simple and easy to perform by providing automated shortcuts that addressed various criticisms gathered during the *needfinding* processes.

5.8 Overall justification

Overall, the redesigned interface not only makes the interface usage simpler but also has the potential to minimize issues with accuracy noted in the *needfinding* method of *reading existing product reviews* (*Section 2.1*). As the redesigned interface minimizes the complexity and the number of steps that the user must take, it significantly reduces issues with measurement accuracy by minimizing inaccurate readings caused by various user errors (e.g., incorrect cuff sizing, improper cuff pressure, wrong placement of the cuff).

6 EVALUATION PLAN

As the redesigned interface (*Section 4*) added new features and modes of interaction in comparison to the existing interface (*Section 3*), the *qualitative evaluation* (Joyner, 2021m) was selected for the evaluation plan. Noting that, the evaluation method of the *survey* will be utilized to evaluate the *high-fidelity prototype* generated above *(Section 4*). The choice to utilize the *survey* method was made as it can be: (1) delivered asynchronously, (2) gathers many responses very quickly in an objective manner, and (3) allows for a quicker interpretation of the results (Joyner, 2021k). Once complete, the *qualitative evaluation* results will be analyzed to determine whether the redesigned interface adequately addressed the *design principles* of *perceptibility*, *flexibility*, *equity*, *ease and comfort*, *feedback*, and *simplicity*.

6.1 Qualitative evaluation plan

The participants of the *survey* evaluation method will be comprised primarily of friends and family members that have monitored, or currently monitors their blood pressure at home, using the *PeerSurvey* tool (King, 2021). The participants will be recruited based on a preliminary questionnaire that determines the following aspects about the individual: (1) whether they have monitored, or currently monitors their blood pressure at home, and (2) whether they are interested in participating in the study regarding blood pressure devices. On that note, if the number of responses from friends and family members is deemed inadequate, the target audience will be expanded to include current and former OMSCS students. In this scenario, the recruitment will be conducted via Slack based on the same preliminary questionnaire noted above.

6.2 Steps to limit biases

In process of designing the structure of the survey and its questions, there are some biases that need to be addressed. First, to minimize the impact of *confirmation bias*, the survey questions will be carefully designed to ensure that they were *clear*, *concise*, *specific*, *expressive*, *usable* while ensuring that the wording of the questions did not conform to the notion of an existing interface having issues with complexity or measurement inaccuracies. Additionally, to avoid risking oversampling of the more extreme views that can cause *voluntary response bias*, the title and description of the survey will be intentionally left imprecise to ensure that the surveys are taken with minimized preconceived notions.

6.3 List of survey questions

Following is the list of survey questions to be asked to the participants:

1. Do you currently, or have in the past, monitor your blood pressure at home?
   (a) Yes (b) No
2. Which blood pressure monitoring device do you use, or have you used?
3. How would you rate the ability to measure blood pressure with the device?
   (a) Very easy (b) Somewhat easy (c) Neither easy nor difficult(d) Somewhat difficult (e) Very difficult
4. How many steps were required to initiate the blood pressure measurement with your device?
   (a) 0-1 (b) 2-3 (c) 4-5 (d) 6+
5. Looking at the *prototype* provided, which of the following components are you able to determine its functionality? (Select all that apply)
   (a) *angled arm rest* (b) *blood pressure indicator* (c) *start/stop button* (d) *cuff pressure indicator* (e) *self-inflating cuff* (f) *elbow contact sensor*

   Please answer the following after reading the *protype component descriptions:*

6. Looking at the *prototype description* provided, did the functionality description match your perceived functionality?
   (a) Yes (b) No
7. The *angled arm rest* will help me identify where to place my arm.
   (a) Strongly agree (b) Agree (c) Neutral (d) Disagree (e) Strongly disagree
8. The *blood pressure indicator* is familiar in comparison to other devices.
   (a) Strongly agree (b) Agree (c) Neutral (d) Disagree (e) Strongly disagree
9. The *start/stop button* is simple and easy to understand.
   (a) Strongly agree (b) Agree (c) Neutral (d) Disagree (e) Strongly disagree
10. The *cuff pressure indicator* will help me identify the status of the device.
    (a) Strongly agree (b) Agree (c) Neutral (d) Disagree (e) Strongly disagree
11. The *self-inflating cuff* reduces the number of steps required for measurements.
    (a) Strongly agree (b) Agree (c) Neutral (d) Disagree (e) Strongly disagree
12. The *elbow contact sensor* will provide assurances of accurate arm placement.
    (a) Strongly agree (b) Agree (c) Neutral (d) Disagree (e) Strongly disagree
13. Any additional thoughts that you would like to share with us regarding the redesign of the *automatic sphygmomanometer cuff* interface?

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