Sakae Yamamoto · Hirohiko Mori (Eds.)

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Editors
Sakae Yamamoto
Tokyo University of Science
Tokyo, Japan

Hirohiko Mori
Tokyo City University
Tokyo, Japan

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Contents – Part I

Information Presentation and Visualization

Environmental Control Units for Inpatient Care at Veterans Affairs Spinal Cord Injury Centers: Heuristic Evaluation and Design Recommendations

Gabriella M. Hancock[1(✉)], Sam Anvari[2], Matthew T. Nare[1], Nicole B. Mok[1], Aram Ayvazyan[1], Kelsey M. McCoy[1], Xiaolu Bai[1], Gregory P. Mather[1], Amanda S. McBride[3], and Natalia Morales[4]

[1] Department of Psychology, California State University, Long Beach, 1250 Bellflower Boulevard, Long Beach, CA 90840, USA
Gabriella.Hancock@csulb.edu
[2] School of Art, California State University, Long Beach, 1250 Bellflower Boulevard, Long Beach, CA 90840, USA
[3] College of Health and Human Services, California State University, Long Beach, 1250 Bellflower Boulevard, Long Beach, CA 90840, USA
[4] Department of Biological Sciences, California State University, Long Beach, 1250 Bellflower Boulevard, Long Beach, CA 90840, USA

Abstract. Heuristic evaluation is a valid and widely accepted method for evaluating system usability. Findings from such evaluations provide valuable insight concerning which system elements should be targeted in future design iterations for improved functionality and user experience. This paper details a heuristic evaluation, utilizing Nielsen's Heuristics and Shneiderman's Golden Rules of Interface Design, of an inpatient environmental control unit used at the VA Spinal Cord Injuries and Disorders (SCI/D) Centers nationwide. Results identified a number of usability issues inherent to the currently deployed interface at varying levels of severity. Design recommendations for addressing these significant issues in future iterations of this system are provided in an effort to foster independence and enhance quality of life in veterans with spinal cord injuries and disorders.

Keywords: Usability evaluation · Heuristic evaluation · User interface · Environmental control units

1 Introduction

The U.S. Department of Veterans Affairs is the federal agency charged with providing any and all healthcare services to eligible military veterans. As a result, it comprises the largest integrated healthcare system in the country. In its mission to provide the highest quality healthcare to over 9 million veterans, the VA has established 14 Cross-agency

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Priority Goals for the future [1]. Four of these goals explicitly address information technology and usability issues with technologies that directly impact veterans: modernizing information technology to increase productivity and security; improving customer experience with federal services; sharing quality services; and improving transfer of federally-funded technologies from lab-to-market [1]. In an effort to support these goals, this project analyzed a multiple-purpose user interface currently deployed throughout the VA's 25 Spinal Cord Injuries and Disorders Centers in order to assess its usability and provide design recommendations for its improvement.

The user interface in question is an autonoME Hospital Environmental Control Unit (ECU; Accessibility Services, Inc., Homosassa, FL). ECUs are "devices that allow individuals who have functional limitations and/or disabilities (such as persons with SCI/D) to increase their independence to control aspects of their environment" [2; pg. 58]. Due to the varying range of functional limitations that result from spinal cord injuries or disorders (SCI/D), the individual needs of each patient are varied and wide-ranging; patients may have paralysis in all four limbs (tetraplegia), or only in their lower limbs resulting in continued use of their hands and arms (paraplegia) [2]. Consequently, the ECU in question includes four modes of interaction to maximize its utility for users with various abilities: a touch interface, sip-and-puff (pneumatic tube), eye-tracking, and voice-control modes. The data herein relate to the touch mode functionality exclusively.

Increased levels of perceived control of environment (via lights/bed functionality), and increased social support (via email/phone/internet functionality) have been forwarded as mechanisms to foster independence and improve subjective well-being [3, 4]. As veterans diagnosed with SCI/D undergo rigorous physical, mental, and emotional rehabilitative care, the effective usability and user experience associated with these technologies is imperative for improving quality of life and alleviating workload of hospital staff. Based on self-reports, patients most often use the systems for watching television and other media, communicating with medical staff, and adjusting their immediate physical environment such as lighting conditions and bed position [5]. Consequently, these were the tasks selected for the current usability assessment. While veterans have reported being largely satisfied with these systems (71%), only 42% of those surveyed felt that this technology met their need for independence [5]. Such a low success rate is most likely due to the prevalence of usability problems inherent to the system. Seventy-five percent (75%) of surveyed users encountered significant problems, identifying the major issues as relating to both the technology (i.e., a non-working system) and the user (i.e., a lack of sufficient training) [5].

Previous usability assessments of Environmental Control Unit (ECU) technologies deployed by the VA note that among the eight identified reasons in which an ECU was out-of-use (ECU was not being used though use was desired), 89% of downtime was due to the patient's need for assistance and maintenance [2]. Problems with startup protocol for ECU use (patient admission, education, and ECU configuration) accounted for 28.8% of this unproductive time, and the remaining 71.2% was due to maintenance (troubleshooting, repair), with troubleshooting alone contributing to 13%-37% of wasted time [2]. Moreover, the majority of staff interactions (51%) with the ECU was due to their necessitated intervention for troubleshooting [2]. Of the issues affecting patients' usability of the system, 53% were considered minor and easily correctable, while 47% of

problems were considered major due to their eliciting long delays, the need for additional resources, or both [2]. Given these serious considerations, this work performed a heuristic analysis on the autonoME ECU interface to identify catastrophic, major, and minor usability issues in order to better inform recommendations for the iterative design of ECU systems that seek to aid veterans in accomplishing necessary tasks, and thereby foster independence as well as better usability and user experience.

2 Methods

Seven evaluators from California State University, Long Beach (CSULB) completed a heuristic analysis of the autonoME Hospital Environmental Control Unit designed to assist SCI/D patients (Fig. 1). Though the system has multiple functionalities, this analysis exclusively addresses those issues raised by interacting via the touch-based mode. The analysis was conducted on operational inpatient systems at the VA Long Beach Spinal Cord Injury and Disorders Center in Long Beach, CA.

2.1 Task Description

Four tasks were selected to simulate typical actions that a patient would expect to make while interacting with the touch control interface of the device, thus assessing the system's range of functionality. These specific tasks have moreover been previously identified as some of the most common tasks for which the system is used [5]. Again, these activities broadly encompass communication with medical personnel, entertainment,

Fig. 1. ECU Home Screen Interface. The display shows the buttons and icons for completing the tasks including the room control, TV, telephone, and interest.

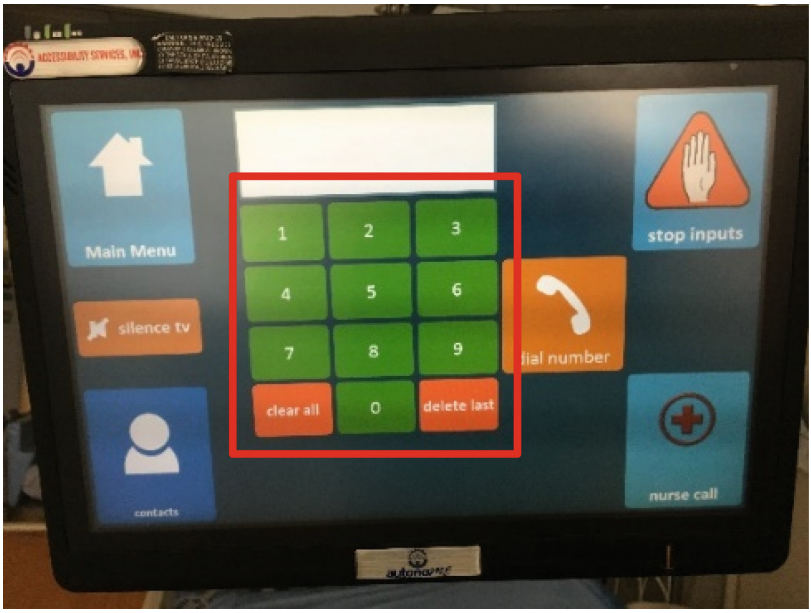

Fig. 2. Display used to enter phone numbers in the ECU call function. Keypad interface is highlighted within the red box. (Color figure online)

and manipulating their immediate physical environment. Therefore, the evaluators used the touchscreen to navigate through the interface in order to: 1) enter a phone number (Fig. 2), 2) send an email (Fig. 3), 3) change the television channel (Fig. 4), and 4) re-position the bed (Fig. 5).

Task 1. The first task was to simulate the steps required for the patient to make a phone call using the ECU's touchscreen interface. Each evaluator used the keypad as illustrated in Fig. 2 to enter their personal phone number to replicate the familiarity the patient would have with entering their physician's phone number.
Task 2. The second task was to compose an email to a medical professional, friend, or family member. Again, without access to veridical email addresses of VA personnel, evaluators performed the task by inputting their own personal email addresses to reflect users' familiarity with their own personal contacts.
Task 3. The third task was to turn on the television screen and then navigate to a particular channel. Despite the presence of shortcut buttons on the television function screen as seen in Fig. 4, evaluators were required to navigate to and change the channel by physically entering channel 20 (i.e., TNT) using the number pad to determine how well manual input completed the task.
Task 4. The fourth and final task was to adjust the head and foot positions of the bed. While the patients do not have the option to change the overall height of the bed, they do have the choice of adjusting various settings in order to sit upright, at an angle, or lay supine.

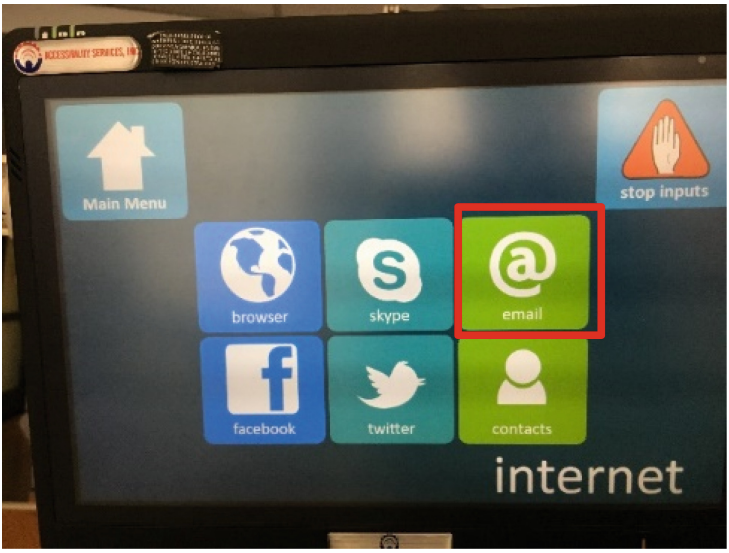

Fig. 3. The display illustrating multiple internet options. The red box indicates the button used to access the email function. (Color figure online)

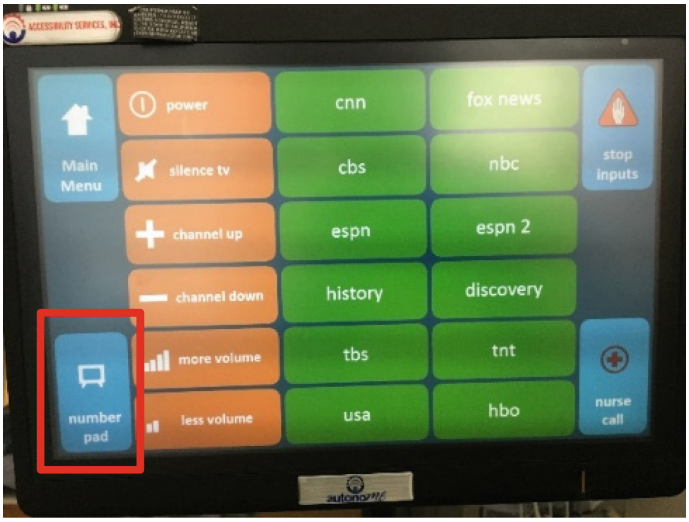

Fig. 4. Red box indicates the location of the number pad button for changing the television. (Color figure online)

Fig. 5. Display options for bed adjustments

2.2 Heuristics

The seven researchers completed their evaluations independently. Each evaluator completed each task twice; the first assessment concentrating on overall work flow, and the second assessment for individual elements of the interface. The interface was evaluated for its adherence to Shneiderman's Eight Golden Rules for Interface Design [6] as detailed in Table 1, and Nielsen's 10 Heuristics for Interface Design [7] as presented in Table 2. The fact that Nielsen's heuristics and Shneiderman's rules share many common principles emphasizes their importance in effective design. After the violations of these heuristics were identified, each violation was rated for severity on Nielsen's Severity Rating Scale [8]. This instrument utilizes a five-point scale (0 to 4) to reflect the importance of the usability issue in terms of frequency, impact, and persistence, and provides a method for quantifying how to prioritize them in the re-design process (and see Table 3). Severity ratings were averaged across evaluators to determine the end rankings displayed in the following tables.

Table 1. Shneiderman's Eight Golden Rules for Interface Design [6].

Number	Rule	Description
S1	Strive for consistency	Information (i.e., icons, colors, symbols, etc.) presentation should be standardized throughout the entire system in order to reduce user confusion
S2	Enable frequent users to use shortcuts	There should be an option for experienced users to be able to expediate task completion

(*continued*)

Table 1. (*continued*)

Number	Rule	Description
S3	Offer informative feedback	The user should always know the status of the system's response by providing feedback to the user based on their completed action (e.g., page loading message or bar)
S4	Design dialogue to yield closure	The users should be presented with the required message that allows them to know when their task has been completed
S5	Offer simple error handling	Error message should be presented with language that explains what error occurred, why it occurred, and what can be done with normal language and not an error code of numbers and letters
S6	Permit easy reversal of actions	The system should allow the user to easily undo any action that was accidental or inappropriate
S7	Support internal locus of control	Users should not be surprised by how the system reacts to their actions. The system should respond in a way that is consistent with a user's expectations for an action
S8	Reduce short-term memory load	The user should easily be able to recognize the information that is being displayed (i.e., icons, symbols, etc.)

Table 2. Nielsen's 10 Heuristics for Interface Design [7].

Number	Heuristic	Description
N1	Visibility of System Status	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time
N2	Match Between System and the Real World	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time
N3	User Control and Freedom	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo
N4	Consistency and Standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions

(*continued*)

Table 2. (*continued*)

Number	Heuristic	Description
N5	Error Prevention	Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action
N6	Recognition Rather that Recall	Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate
N7	Flexibility and Efficiency of Use	Accelerators—unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions
N8	Aesthetic and Minimalist Design	Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility
N9	Help Users Recognize, Diagnose, and Recover from Errors	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution
N10	Help and Documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large

Table 3. Nielsen Severity Rating Scale [8].

Rating	Description
0	Not a usability problem
1	Cosmetic – only fix if time allows
2	Minor – low priority fix
3	Major – high priority fix
4	Catastrophe – imperative to fix

3 Results

After reviewing the environmental control unit, the identified usability issues were categorized as either catastrophic, major, or minor by taking the average of the evaluators' severity ratings. Four catastrophic, eight major, and fifteen minor usability issues were identified (Fig. 6). For the sake of clarity and brevity, only the three most severe usability issues from each category will be herein discussed.

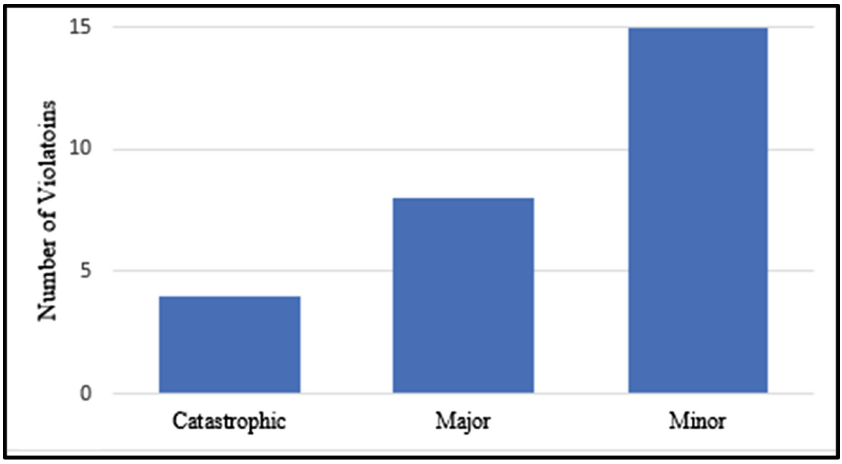

Fig. 6. Frequency counts of catastrophic, major, and minor usability violations.

3.1 Catastrophic Usability Issues

As illustrated in Figs. 7 and 8, the screens for dialing phone numbers or selecting TV channels have no option to "go back" to the previous screen or undo selections. As a result, users are forced to return to the home screen and again navigate through any and all screens to reach their previous decision point and select another option. With no capability to move backward in the workflow, users waste time and energy going through the process a second time and can become frustrated (Table 4).

While writing an email, no assistance is provided for completing tasks such as logging in or inputting contacts, nor is there support when the system experiences server connection issues. Figures 9 and 10 show the lack of "Help" options in any email-related menus. Such a lack of feedback as to how to troubleshoot issues leaves users confused about how to effectively progress in the workflow, and increases the likelihood that they will have to ask medical staff for assistance as help tools are not available through the system. While attempting to send an email, the system experienced server login issues which prevented the fabrication of email or even drafts. Again, no feedback or help was offered to address how the user could mitigate the server login issues. As a result, users could not even begin the task.

Fig. 7. Images of interface for dialing phone number (left)

Fig. 8. Selecting TV channel (right).

Table 4. List of top three Catastrophic Usability Issues with heuristic violations and final average severity ratings.

Issue	Heuristics violated	Rating
Phone Dial/TV dial menus lack dedicated "Go Back" button. Phone screen lacks button entirely; TV menus do not label them consistently (e.g., "favorite channels" instead of "go back")	N3, N5, N7; S5, S6	4
No help documentation in case user has a problem or needs to troubleshoot (e.g., when having server/login/email contact issues)	N9, N10; S3	4
No system feedback given to user for troubleshooting issues (e.g., unable to login to server)	N1, N3, N5, N9; S3, S4, S5, S6	4

Fig. 9. Images of interface for selecting email function (left)

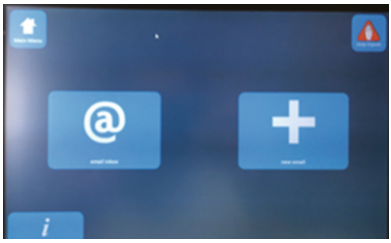

Fig. 10. Starting email composition (right).

3.2 Major Usability Issues

Contacts must be added to the system prior to composing emails; however, the system does not provide the user with any instruction regarding this requirement. Without being told of this stipulation, users can waste time attempting to begin a draft of the body of the email and become confused when this is not possible due to a missing contact (Table 5).

Table 5. List of top three Major Usability Issues, with heuristic violations and final average severity ratings.

Issue	Heuristics violated	Rating
User must input and save contact before they are allowed to compose an email. System does not give feedback/inform user of this requirement	N1, N2, N7, N9, N10; S3, S7	3
Interface uses Red and Green as key colors for function coding; can be detrimental to Red/Green colorblind individuals	N2, N4, N7; S3	3
In email menus: "Jump Back" button does not work properly; can sometimes send user back several screens in email writing process	N3, N5, N7, N8; S2, S5, S6	3

Furthermore, multiple menus rely on red and green color-coding for key functions. Figures 11 and 12 demonstrate this color scheme for multiple screens of the phone call task. Confusion can arise as green buttons that users depress briefly flash red, which can confuse users as to which button has actually been pushed. Red-green is the most common congenital color vision deficiency and it disproportionately affects males [9]. As US male veterans outnumber female veterans (16.3 million versus 1.6 million) [10] and self-reports identify 95% of users as male [5], this design choice places the typical user at as significant disadvantage for navigation and interpretation of system feedback.

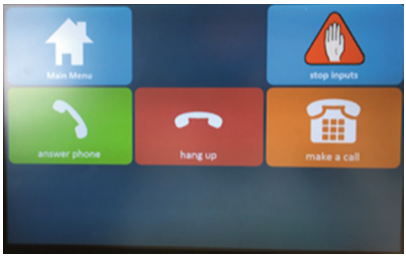

Fig. 11. Interfaces for choosing phone dialing function (left) (Color figure online)

Fig. 12. Inputting phone number (right). (Color figure online)

While in the process of composing an email, the "Jump Back" button can work improperly. If the user is composing an email after a contact is input, they are sent back to the menu seen in Fig. 10. After selecting to compose an email, should the user press "Jump Back", they will not be sent back to the immediately previous menu found in Fig. 10. The user is instead sent back several screens to where they first initiate the process of inputting contacts (Fig. 10).

3.3 Minor Usability Issues

Figures 9, 13 and 14 illustrate how the ECU has no feature to give users feedback for a chosen channel. The only way to determine if the desired channel is actually selected

is to have the TV next to the ECU on and visible. Figure 15 shows the home screen and how, in order to access email functions found in Fig. 16, users must first press the "Internet" button on the screen to send an email. This design makes it more difficult to find email function. Moreover, while dialing the phone or selecting a channel, pressing green buttons provides feedback by turning red. Figure 17 shows how this scheme can be confusing as buttons such as "Clear All" and "Delete" are present and coded in red. Seeing only a collection of red buttons may therefore confuse the user as to which button has in actuality been depressed (Table 6).

Fig. 13. Interfaces for selecting TV channel by inputting channel number directly (left)

Fig. 14. Using channel shortcuts (right).

Fig. 15. Interface of ECU home screen (left)

Fig. 16. Location of email function in "Internet" sub-menu (right).

Fig. 17. Image of the keypad used for entering the phone number. (Color figure online)

Table 6. List of top three Minor Usability Issues detected, with heuristic violations and final ratings.

Issue	Heuristics violated	Rating
When selecting TV channel; ECU gives no feedback that task was successful. User must check TV to ensure success; needs element displaying 'TV now on channel "X"'	N1; S3, S4	2
User must press "Internet" button first before finding "email" button; user may not be aware, and might be hard to find the email button	N1, N2, N3; S3, S9	2
For dialing numbers (e.g., phone/TV channel); Numbers are green, while "Clear All"/"Delete" buttons are red. Pressing green buttons give visual feedback by turning red. Can be confusing, given that buttons turn the same color as the delete functions	N1, N3; S3	2

4 Discussion

4.1 Major Findings

The frequencies of usability violations identified in the heuristic evaluation of the ECU interface are illustrated in Fig. 6. In terms of severity, 15% of the usability problems were categorized as catastrophic, 30% were major usability problems, and 55% were minor usability problems. For catastrophic violations, the three most violated heuristics were "user control and freedom," "error prevention," and "offer informative feedback."

The most important catastrophic usability issue was the lack of a dedicated "go back" button across screens. As shown in Figs. 7 and 8, the screens for dialing a phone number and selecting a TV channel completely lack the "go back" button. Without this control, the user is unable to recover from navigation errors without backtracking to the home page. For veterans with spinal cord injuries and other special populations with severe motor skill impairments, using the ECU provides users with communication and entertainment benefits, however, using the ECU necessitates significant cognitive effort. Using an inflexible system that restricts user control and freedom increases cognitive load and causes user frustration [11]. As a result, this can negatively impact the user's ability to effectively engage with the system and accomplish task goals. To address issues of user interface inconsistency, the authors propose the inclusion of a permanently visible, clearly defined backward navigation button (e.g., "go back") at the top of every screen that returns the user to the previous screen. The "go back" button should always be available, in the same location, and work in the same fashion, allowing the user to retrace one step at a time rather than restarting the task every time [12]. Additionally, the button should be a fairly large target, especially when designing for users with motoric impairments, who benefit greatly from having a large target [12].

The second catastrophic issue identified was the absence of help documentation when the user runs into an error, as shown in Figs. 9 and 10. The lack of help documentation can impede the user's ability to use the system correctly [13], especially when the user

is not in the presence of a healthcare provider. Help documentation is also critical for nurses and healthcare providers who are required to learn how to use the system prior to teaching their patients [5]. As a result, not being able to troubleshoot errors while learning how to navigate the ECU can lead to faulty training when teaching patients how to use the device. A clearly defined "Help" button should be made visible throughout the application. It should be designed to allow the user to search for context specific information relevant to their issue by clicking on a drop-down menu. Instructions for troubleshooting issues should consist of clear, consistent, sequential, and actionable items that instruct the user on how to perform the task.

The final catastrophic problems were the lack of informative system feedback given to the user when troubleshooting errors and the inability to login and draft an email due to no internet connection/no offline mode. When attempting to login and draft an email without internet connection, the user receives an error ("Unable to login to server"). However, this error message does little to assist the user in diagnosing and solving the system issue. Such confusion can hinder the user's ability to understand, detect, and manage the appropriate errors when they occur [14].

Effective feedback should keep the user informed of system state at all times [7]. An error message should be designed to give the user troubleshooting options on how to connect to the server and list specific instructions on how to manage the connectivity error. If the issue persists, an additional option should provide the user with instructions on how to contact a product representative for the autonoME Hospital Environmental Control Unit or a service provider to troubleshoot the connectivity issue.

A major usability issue was the lack of system feedback to inform the user that he/she is required to add a new contact to the system before composing an email. Lack of informative feedback to enter information in a mandatory data entry field can lead to user frustration and dissatisfaction. To bypass this issue, the system should be designed to either restrict the user from inputting text in the email body section prior to entering a new contact or instruct the user to enter a new contact first, prior to composing an email. A design element of emphasis that highlights the first step of completing the task, such as a red box around the specific section to be completed should be implemented, while also making other sections inaccessible by greying them out.

The second major usability issue is the interface's color coding. Using color for function coding is unfavorable for users with color vision deficiencies. The interface relies on color to convey a message. For example, Fig. 11 demonstrates the use of red for "hang up" and green for "answer phone". Certain users with red-green color vision deficiencies might have difficulties distinguishing the colors on the buttons and have to read the text instead. Thus, the color-coding in the interface is inefficient and lacks accessibility for different user populations. A suggestion is to use both color and symbols to indicate the purpose of a button. In addition, in order to prevent the users from choosing the unwanted function by mistake, all the buttons should clearly describe the location where users will be redirected. For example, the "Jump Back" button in the email menu would send the users several screens back, instead of only to the previous one. For users who intend to go back to the previous screen, this design causes confusion and frustration. To improve efficiency, the button name can be changed to the location that will be redirected to, such as "Main Menu".

Minor usability issues are the violations that receive the lowest priority for fixing, though failure to identify and address these issues can still cause negative user experiences. For instance, the system should always keep users informed about the system's status after a selection. However, the interfaces failed to provide feedback when selecting TV channels. If users are uninformed about the current channel, they might waste effort on clarifying whether they have successfully made the desired selection. Thus, the interface should contain a message about current channel selection. In addition, the design of the menu should match users' past experiences. The evaluators found difficulties related to the location of the "Email" button as it is listed on a secondary menu that is accessed after the "Internet" button has been selected, while the "Telephone" button is listed as an option on the primary menu. This layout is inconsistent with our mental models of the email function as a primary option on the home screen, prioritized in other touch-centric interfaces (i.e., smartphones and tablets). Therefore, we recommend moving the "Email" button to the primary menu and place it next to the "Telephone" button. Furthermore, the interface should be consistent and eliminate any ambiguous or confusing feedback. However, evaluators found the current design to be misleading for users due to the green buttons flashing red when pressed, changing to the same color as the "Clear All" and "Delete" buttons. A recommendation is to simply darken the same color when pressing button (i.e., green flashes a darker green).

4.2 Continuing Line of Research: Next Steps

The goal of this project is to research various user interface design approaches and standards for the purpose of enhancing the usability of the ECU device, with VA Hospital patients in the SCI/D Centers as the target user-base. The authors plan to accomplish this goal in multiple phases, beginning with this heuristic evaluation of the design of the currently deployed ECU system. In the upcoming second phase, the authors will administer validated questionnaires and conduct structured and semi-structured interviews with end-users to examine usability issues. In the third phase of the project, the authors will re-design the ECU digital interface in keeping with Nielsen's heuristics, Shneiderman's golden rules, and end-users' input from the second phase. Interactive prototypes will be generated to conduct A/B user testing to measure the effectiveness of the design and user experience. Systems will be evaluated for task completion rates and times across myriad tasks that necessitate interacting with elements both within and outside of the VA hospital. The final phase of this research project is to test the effectiveness of the CSULB re-designed user interface with end-users (i.e., Veterans), VA Staff, at-home caregivers, and CSULB students for comparisons of usability in a general population. Findings will facilitate the empirically-driven re-design of such systems to improve the independence and quality of life of our veterans and other stakeholders of the ECU system (i.e., both inpatient and outpatient caregivers).

5 Conclusion

Veterans with spinal cord injuries and diseases typically find environmental control units to be useful technological tools [5]. However, the current design and functionality of

these systems suffer from numerous usability issues that compromise performance and undermine a strong sense of independence in its intended end users, our veterans [5]. The heuristic analyses herein evaluated this system's usability across a range of different tasks to identify specific design elements that led to these undesirable outcomes. Results indicated that the interface currently has issues ranging in severity from relatively minor to catastrophic. Design recommendations for rectifying these violated heuristics and enhancing usability were provided to ensure that veterans' technological support tools are designed in such a way that promotes successful task completion, fosters independence, and decreases workload and frustration for veterans and hospital staff.

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