USABILITY TESTING OF A MOBILE HEALTH APPLICATION (THROMBO-LINK)

EVALUATING THE USABILITY OF A MOBILE APPLICATION (THROMBO-LINK) FOR PERIPROCEDURAL MANAGEMENT OF ANTICOAGULANT MEDICATION

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TITLE: Evaluating the Usability of a Mobile Application (Thrombo-Link) for Periprocedural Management of Anticoagulant Medication

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Lay Abstract

It is estimated that each year 10% of patients who use blood thinning therapy need to interrupt their medication to undergo surgery. This study focuses on how easy it is to use a mobile application (Thrombo-Link) that was designed to manage the process of interrupting these medications. We wanted to identify shortfalls of the application. This study used methods that made sure the application did what it was designed to do without risking patient safety. A team of usability experts did the heuristic evaluation using Jakob Nielsen's methodology. The end user participants were staff from Hamilton General Hospital bridging clinic. Both testing approaches helped us find ways to make the application work better for the people who would be using it.

Abstract

BACKGROUND: Peri-operative anticoagulation management plans reduce the risk of bleeding and thrombotic events in patients who are on anticoagulation therapy and undergoing surgical procedures. A mobile application (Thrombo-Link) has been developed as a clinical decision support tool to aid healthcare professionals in providing these management plans. Little literature exists exploring the usability of such an application.

PURPOSE: The purpose of this thesis is to examine: 1) How Jakob Nielsen's 10 Usability Heuristics can be used to identify usability shortfalls of the Thrombo-Link application to improve subsequent iterations, and 2) the role of end user testing in further identifying usability issues of the Thrombo-Link application in a clinical setting.

METHODS: This study included the participation of three usability experts and five staff from the Hamilton Health Sciences peri-operative anticoagulation management clinic. Usability experts utilized Jakob Nielsen's 10 usability heuristics to identify usability shortfalls of Thrombo-Link which were conveyed to the software developer. Iterative changes were made to the application. During the end user testing, participants were asked to use the application as they would in the clinic and completed the system usability scale (SUS) to assess the overall usability of Thrombo-Link.

RESULTS: A total of 51 usability issues were identified by the heuristic evaluators and 7 usability issues were identified by the clinic staff. Clinic staff rated the application with a median answer of 5/5 on the SUS in terms of ease of use.

CONCLUSIONS: Both Nielsen's heuristics and end user testing identified usability concerns within the Thrombo-Link application which were addresses by iterative software development. This furthers our understanding of the usability of this clinical decision support tool.

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List of Acronyms and Abbreviations

App – Application, usually a mobile software application

CAD – Canadian Dollars

CDSS – Computerized Clinical Decision Support Systems

COVID-19 – 2019 Coronavirus Pandemic, SARS-CoV-2

DOAC – Direct Oral Anticoagulation Medication

eHealth – Electronic Management of Health

EHR – Electronic Health Record

EMR – Electronic Medical Record

HGH – Hamilton General Hospital

INR – International Normalized Ratio

mHealth – Mobile Health

SD – Standard Deviation

UASAD – User Acceptance and System Adaptation Design

UI – User Interface

UX – User Experience

Declaration of Academic Achievement

The following is a declaration that the work presented in this thesis was completed by Fady Said. Guidance at all stages of the research (study design, data collection, data analysis) conducted for this thesis was provided by Dr. Vinai Bhagirath, Dr. Cynthia Lokker, and Dr. Christopher Hillis. Fady Said was responsible for writing this manuscript. Dr. Vinai Bhagirath, Dr. Cynthia Lokker, and Dr. Christopher Hillis contributed to manuscript review and revision.

Introduction and Background

Overview

The Hamilton General Hospital Peri-operative anticoagulation management clinic focuses on the safe management of anticoagulation medications for patients that undergo a procedure. This clinic provides service to over 1200 patients on an annual basis and has one clerk, two bridging physicians, and four nurses working within the clinic. To help standardize practice and improve efficiency of documentation in the clinic, a clinical decision tool (Thrombo-Link) was developed for use in the clinic. The Thrombo-Link application (app) is a mobile health (mHealth) app that is accessible through a mobile device web browser. This thesis describes the usability testing of the Thrombo-Link application.

Mobile Apps in Healthcare

mHealth applications are mobile applications designed to be used by patients and health professionals to aid in the promotion of health outcomes[1]. The benefits of mHealth apps are that they provide quick and easy access, transfer, and tracking of health information. A limitation of mHealth apps is that they require expensive technological hardware to be utilized[1]. They can be used for collection, tracking and display of patient information (diabetes blood sugars, blood pressures); communication capabilities; information resources (textbooks, medical literature); and clinical software applications (disease diagnosis aids, medical calculators, and clinical decision support systems.)[1].

Computerized Clinical Decision Support Systems

Computerized clinical decision support systems (CDSS) are software designed to be a direct aid to clinical decision making, in which the characteristics of a patient are matched to a computerized clinical knowledge base and patient specific recommendations are then presented to the clinician for a decision[2]. Benefits of CDSS include increased patient safety, enhanced clinical management, cost containment, diagnostic support, and administrative automation[2]. Drawbacks of CDSS include alert fatigue, negative impact on user skill, system maintenance, and content challenges[2]. Computerized clinical decision support systems (CDSS) can aid clinicians in the complex decision-making process that is involved with patient care[2]. Since their inception in the 1980's, clinicians have used CDSS to create a more streamlined and systematic approach to diagnosing and treating patients[2]. For example, the DAWN AC software tool is a clinical decision support aid that helps determine a safe dosage of anticoagulation therapy[3]. CDSS further provide healthcare professionals with patient specific recommendations and guidelines for disease diagnosis and treatment, by integrating evidence-based medicine practices to the CDSS software[4].

Despite their potential benefits, CDSS still suffer from limitations and low adoption by healthcare professionals due to their complex nature and unintuitive user interface[5]. User acceptance has been identified as a major limiting factor to adoption of these novel healthcare technologies[5]. Some healthcare professionals may not have adopted the use of CDSS due to clinical workflow constraints. CDSS may sometimes be complicated and lack a user-friendly approach; because of this, clinicians may feel less inclined to adopt these systems in daily practice. Moreover, it is evident with an aging physician population that computer literacy may be a hindrance to the use of new technologies[5-6]. Physicians are more likely to adopt CDSS if the

systems match their own decision processes[5,7]. Thus, it is crucial to involve physicians and other healthcare professionals in the development of CDSS.

User-Centered Design

Maintaining a user-centered design during development of CDSS is important to ensure that users can complete their tasks in an efficient manner[8]. The main goal of designing user-centered software is to develop tools and user interfaces that consider the characteristics of the end users and their task[8]. Creating a well-developed user interface is challenging because the usability of the system impacts whether or not an application is adopted or abandoned[8]. This can be done by applying the User Acceptance and System Adaptation Design (UASAD) for CDSS technology design. This model can be used to ensure that clinical workflow and decision-making processes are followed to enhance adoption of newly developed tools[5,9]. Within the UASAD are different methods in which developers can ensure a user centered design for their app including focus groups, user-acceptance testing, surveys, and usability testing[5,8-9].

System Usability and Heuristic Evaluation

Given the challenges in adoption of CDSS, usability issues arise when implementing eHealth interventions and other technologies in clinical settings[10-11]. Usability is the extent to which a system can be used by its desired user to achieve a specific goal with effectiveness, efficiency and user satisfaction[12]. Methods for evaluating usability can be classified as inspection methods, which are conducted by usability analysts and include cognitive walkthroughs and heuristic evaluations, and end-user testing which involves representative users of the system[10-14]. CDSS that have not undergone usability testing may suffer from increased risk of errors,

inefficient or frustrating user experience which may limit uptake, and risks to security of information[15].

Using inspection methods can be beneficial as they increase efficiency by reducing the number and duration of end-user tests[16]. Cognitive walkthroughs are a group-based task-focused method where experts emulate user problem solving abilities to uncover system deficiencies[16]. Although cognitive walkthroughs are able to uncover 80%-85% of usability issues, they require multiple group sessions, are task-focused, and cost more than other usability testing methods[16]. Heuristic evaluation, a process whereby experts do independent walkthroughs of systems and apply rules of thumb to measure the overall usability of interfaces and then report any issues they encounter, is a widely researched method that has been used for assessing the usability of eHealth interventions[11]. One of the major benefits is that it facilitates cost-effective identification of overall usability and design issues[11,13]. Another benefit of heuristic evaluation is that only one session per evaluator is required to identify issues, compared to cognitive walkthroughs which require multiple task focused sessions to identify usability issues[10-11,13]. Guidelines for developing good user interfaces have been refined by two heuristic evaluation experts; Jakob Nielsen's 10 Usability Heuristics for User Interface Design and Gerhardt-Powels' Cognitive Engineering Principles[10-11,13]. During heuristic evaluation and analysis, design characteristics that violate one or multiple heuristics are commonly identified. For each usability issue, the evaluators identify the potential complications that will arise as a result of the issue[11,13].

Few studies directly compare Nielsen Heuristics to Gerhardt-Powel's Cognitive Engineering Principles[17-18]. Both have common factors including looking for consistency, task match, appropriate visual presentation, user control, memory-load reduction, handling errors,

guidance and support[18]. Studies have shown that the Gerhardt-Powel method has the potential to uncover more low risk severity issues when compared to Nielsen's evaluation method[11,18].

Nielsen's heuristics mostly stem from design guidelines and refer to the system's user interface and encompasses 10 heuristics for categorizing usability[17-18]. Nielsen's first heuristic is the visibility of system status. This heuristic refers to how well the state of a system is conveyed to its users. Systems should always keep users informed to what is going on[19]. Nielsen's second usability is the match between the system and the real world, the system should speak the user language with words, phrases, and concepts that are familiar to the user. User control and freedom is the third of Nielsen's usability heuristics; the heuristic claims that users often choose system functions by mistake and require a clearly marked method to leaving the unwanted state. The fourth usability heuristic is adherence to consistency and standards; this heuristic maintains the learnability of the application to new users[19]. The fifth heuristic is error prevention; this heuristic is crucial to the safe design of eHealth technologies due to the prevalence of preventable errors in clinical practice. Recognition rather than recall is another essential heuristic as users often have an easier time recognizing necessary inputs rather than recalling information from memory. This heuristic ensures that the information is presented to the user rather than the user having to recall the information causing cognitive fatigue. The seventh usability heuristic is flexibility and efficiency of use, this includes keyboard shortcuts and auto-fill options within the application to make the app easier to use. To make apps easier to use, the eighth heuristic of aesthetic and minimalist design is applied. Having good aesthetic and minimalist design to the app will allow the user interface to be more simple and easier to use by only incorporating the essential functions[19]. The ninth usability heuristic identified by Jakob Nielsen is helping users recognize and recover from errors. This heuristic encompasses clearly informing users when an

error has occurred and also providing them with the steps to recover from the error, which is usually done with an error message[19]. The final usability heuristic is help and documentation, this provides users with an intuitive design that includes instructions and help when navigating through an application[19]. Any usability issues that arise during heuristic evaluation as assigned a heuristic category and a severity rating. The severity ratings have a range of 0 (non-usability issue) to 4 (catastrophic usability issue that must be resolved before launch)[19].

Nielsen's Heuristics evaluation is an effective method of identifying the potential usability constraints that may arise when using an eHealth application[13]. Usability experts and content experts are the evaluators participating in the usability assessment of the application, so that a variety of usability issues maybe identified within each evaluator's professional domain[20]. Jakob Nielsen's methodology for usability heuristics can be conducted with a limited amount of experts[20]. Empirical data reveals that there are diminishing results of identified usability issues with an increased amount of evaluators[20]. Thus, between three and five evaluators is ideal for uncovering 75% of all usability issues within the tested application[20]. In contrast to most heuristic schema, Gerhardt-Powel intends that the usability guidelines be directly based on cognitive principles[17-18].

Several factors affect both types of heuristic methods in practice. These factors include evaluator training, evaluator knowledge of the application, problem identification and extraction, as well as task coverage and severity identification[18,21]. If these factors are optimized, an iterative process of heuristic testing and application development before end user testing can reduce the financial burden of implementing digital health apps in a clinical setting[13,17-19,21-22]. The mentioned financial burden is reduced as fewer iterations of the application will be required during the end user testing phase[18-19,21-22]. However, additional end user testing must be

completed after heuristic evaluation to ensure a user centered design approach is used to implement healthcare technologies that clinicians and other healthcare professionals may utilize in practice[13].

System Usability and End User Testing

End user usability testing is a human factors method that allows for the evaluation of how a technology will function in a contextual setting. The main objective is to identify problems relating to ease of use, accessibility, and overall effectiveness of the healthcare technology to alleviate risk and safety issues[13]. Usability testing is conducted in a low fidelity simulated environment with representative end user interaction. The end user representative may be physicians, nurses, clerks or patients, depending on the intended functionality of the application[13]. No matter how effective heuristic evaluation may be, it is impossible for one to identify all problems or potential risks that may arise in practical use of CDSS or its application in a clinical setting. This is due to the heuristic evaluation being conducted in an isolated environment without end user expertise or input[13,17-18]. Thus, it is crucial for end user testing to be conducted before the system application is launched in the clinical setting[23].

End user testing allows for the insight into the demographics of the end users, acceptability and adoption of the application, as well as the overall usability of the application[24]. Perceived usability will vary depending on the expectations and intentions regarding use of the technology by specific end users. The unified theory of acceptance and use of technology (UTAUT) is a model that has been used in numerous contexts to explain user intentions and expectations toward information systems technologies, which has been shown to predict adoption of information technologies[24-26]. The UTAUT model explains users' attitude towards

new technology with the following constructs: 1) performance expectancy, 2) effort expectancy, 3) social influence, and 4) facilitating conditions[25]. These constructs have been expanded to include hedonic motivation, perceived value, and habit[26]. The key constructs influence behavioural intention and actual use behaviour. For an end user group with defined expectations and intentions, the usability of a technology can be summarized using tools such as the System Usability Scale (SUS)[24].

It is essential to maintain a user-centered design when iterating new healthcare technologies, otherwise applications or systems will not function as intended and will fail to be adopted by its intended user[23]. Insight on the potential adoption of new mHealth technologies can be gained through end user technical walkthroughs and applying think aloud methodologies. These methodologies allow end users to interact with the application during the development cycle while also providing information on how end users experience the application UI or functionality[27].

Health technologies, especially new and emerging mobile health (mHealth) technologies are promising tools for documentation, decision making and intervention management in direct clinical settings[13,23,28]. Untested mHealth technologies may hinder results in positive behaviour change, system adoption, risk mitigation, patient safety and as a result, fail to accomplish the protonated objective and ultimately yield adverse health outcomes[23,28]. A CDSS for management of anticoagulant medication around the time of invasive procedures (Thrombo-Link) had been developed but required usability testing prior to implementation. Usability testing of this CDSS forms the subject of this thesis.

Periprocedural Management of Anticoagulation

Anticoagulant medications are used to treat and prevent thromboembolic (blood clotting) events; however, they increase the risk of bleeding and therefore often cannot be used around the time of a surgical procedure. Up to 250,000 or 10% of patients on therapeutic anticoagulation in North America require interruption of their anticoagulant medication due to need for an invasive procedure annually[29]. Patients who are not provided with instructions to interrupt their anticoagulation therapy peri-operatively have a 3%-4% excess risk (above the baseline risk of <1.5%[30-31]) of a life-threatening bleeding event than those patients who have received bridging services[32]. Overall, anticoagulants are the top cause of medication related harm in terms of emergency visits, hospitalizations, and fatalities worldwide[33-34]. There are costs of inadequate bridging to the patient, physician, and the healthcare system[34]. The direct medical costs alone of an anticoagulant associated bleed are over $11,000 CAD per episode[34-35]. Thus, it is critical to bridge peri-operative patients safely to ensure efficiency of the healthcare system and avoid unnecessary healthcare expenses.

Based on clinical trial evidence, a Canadian non-profit society dedicated to improving care of patients with thrombosis through knowledge translation activities - Thrombosis Canada - makes a clinical decision tool available to clinicians that provides robust guidance on how to bridge complex and emergency peri-operative patients[30,36-37]. This high level, web-based tool is a CDSS and uses algorithms that physicians and nurses may incorporate into their practice to minimize risk and increase patient safety. However, this CDSS is not suited for integration into a hospital information system and does not produce any personalized documentation. The Hamilton General Hospital perioperative anticoagulation management (bridging) clinic has recently adapted the Thrombosis Canada CDSS, expanding its functionality to allow production

of individualized documentation for both the patient and healthcare professionals, with a goal of eventual integration with the electronic medical record. It was designed to be accessed via tablet or desktop computers via a web browser. This tool, called Thrombo-Link, required usability evaluation to maximize its safety and impact.

Thesis Aims and Objectives

This thesis aims to explore the use of Nielsen's Heuristic evaluation method followed by iterative app development and end-user testing to identify usability and safety issues in a CDSS. The specific objective was to perform heuristic testing using Nielsen's method followed by end-user testing on the Thrombo-Link app to elucidate challenges and limitations of this methodology.

Methods

Overview of Study Design

This thesis was a part of the Thrombo-Link UT Study (Usability testing and iterative design of an electronic program to aid in peri-procedural management of anticoagulant medication) conducted over the 2020-2021 academic year during the COVID-19 pandemic. The Thrombo-Link UT Study is a usability testing and iterative design study meant to improve the usability of a mobile based CDSS called "Thrombo-Link", developed by ZLTechnovation for the Hamilton General Hospital (HGH) peri-operative anticoagulation management clinic. This app is designed to be a clinical decision support tool for clinicians who provide bridging recommendations to help standardize care for peri-operative management of anticoagulation medication. The user testing comprised two phases: heuristic testing and end-user testing, with iterative revision of the Thrombo-Link app after each phase.

Heuristic Testing

Recruitment of Evaluators

Evaluators for heuristic testing were selected based on expertise in the following domains: user interface (UI); user experience (UX); and peri-operative anticoagulation. For convenience, these were selected from among the contacts of the project supervisor. Purposive selection was used to ensure that at least one expert from each domain was recruited. It was decided *a priori* to select 3 evaluators, as this has been demonstrated to detect 75% of issues; using a greater number of evaluators brings diminishing returns in terms of issues identified[20]. Evaluators were approached for participation in the study by the M.Sc. student using a telephone

script (Appendix A). Evaluators provided informed consent (form in Appendix C), and other session data were collected (case report form Appendix D).

Selection of Heuristic Scheme

The heuristic of Nielsen was employed[19]. A non-systematic literature review was conducted using the PubMed database, and a heuristic scheme was selected based on ease of use, documented previous use for clinical decision tools, tested validity, ability to detect discrete usability issues, and the ability to be executed virtually via videoconference. The original heuristic was used without modifications, as it has been well-described when used unmodified for clinical decision tools[19].

Performance of Heuristic Testing

Heuristic evaluations were conducted using Zoom videoconferencing software. The evaluators navigated the Thrombo-Link app using an Apple iPad 10.2 Model #A2428 via the Chrome browser. Audio and screen recording was taken. Heuristic evaluators were oriented to the Nielsen's heuristic methodology, to the hardware device, to the Thrombo-Link app, and to the report form used to compile issues (Appendix E). Evaluators were prompted to categorize each issue according to the heuristics and to score it by severity. Severity was scored on a scale of 0 to 4; where 0 is not a usability issue to 4 which is a catastrophic usability constraint and must be fixed before launch. Evaluators were not required to record their own written comments; rather, verbal comments from the evaluator were recorded and transcribed by the observer to reduce cognitive load on the evaluator[20,38]. Evaluators progressed through the

Thrombo-Link app at least twice. Evaluation continued until the evaluator felt there were no further issues.

Table 1. Heuristics scored by evaluators, with severity range 0 to 4 (0= no issue, 4 = catastrophic usability issue).

Heuristic
Visibility of System Status How well the state of a system is conveyed to its users. Systems should always keep user informed to what is going on
Match between System and Real World The system should speak the user language with words, phases, and concepts that are familiar to the user
User Control and Freedom Users often chose system functions by mistake and require a clearly marked method to leaving the unwanted state
Error Prevention Eliminating error prone conditions and creating a design that prevent problems from occurring in the first place
Recognition Rather than Recall Ensures that the information is presented to the user rather than the user having to recall the information causing cognitive fatigue
Flexibility and Efficiency of Use This includes keyboard shortcuts and auto-fill options within the application to make the app easier to use
Aesthetic and Minimalist Design Interfaces should not contain information which is irrelevant or rarely needed. Allowing the user interface to be simple and easier to use by only incorporating the essential functions
Consistency and Standards maintaining the learnability of the application to new users is important to maintain high standards and consistency
Help Users Recognize, Diagnose, and Recover from Errors Error messages should be expressed in plain language, precisely indicating the prom, and constructively suggesting a solution.
Help and Documentation It is necessary to provide documentation to help users understand how to complete the task or use the system

Aggregation of Issues Discovered During Heuristic Testing

The MSc. student aggregated a list of issues from all of the evaluators, and then compiled a single list of unique issues. The evaluators then reviewed this list via videoconference and a project development communication platform (Jira Software[39]), and discrepancies in severity scoring between evaluators were resolved by consensus. Each item from the finalized list was introduced as a separate "ticket" through the Jira Software[39] which was ordered by severity. Each ticket was sequentially addressed by the development team. Communication between the development team and the MSc. student was conducted via Jira Software[39]. Once all issues were addressed, the evaluators reviewed the product, and consensus was obtained on proceeding to end user testing.

End User Testing

Recruitment of Testers

All staff (clerks, nurses, and physicians) who worked in the Hamilton General Hospital (HGH) Peri-operative Anticoagulation Management Clinic were eligible and asked to be participants of the end user testing. The study was introduced to potential participants by the Principal Investigator of Thrombo-Link UT. Those agreeing to be contacted were then approached by the MSc. student using a telephone script (Appendix A). The study protocol was reviewed (Appendix B) and informed consent was obtained using a consent form (Appendix C).

End User Testing Methodology

End user testing was conducted with the HGH perioperative anticoagulation clinic staff. After consent was obtained, baseline data were collected, including demographics and a questionnaire assessing acceptance of mobile technology based on the UTAUT model (Appendices D and F). The testing was conducted via the Zoom videoconference software on an Apple iPad 10.2 (Model #A2428) hardware via the Chrome web browser. Each end user was instructed to use the Thrombo-Link application as they would in clinic, and to make think-aloud comments on their actions while also observing any usability issues. A specific hypothetical patient case was not employed – the testers could enter any data they wished to test the functionality. This was done to allow testers to have the control and freedom over the information they were inputting into the application. There was one session per tester and only one walkthrough of the application was conducted in each session. Audio as well as video of the tester's screen was recorded for each session. At the end of each session, the system usability scale (SUS) was administered (Appendix G). Each recording was transcribed, and individual issues were extracted by the MSc. student.

Analyses

Descriptive statistics were applied to demographic characteristics, duration of sessions, and questionnaire scores for the heuristic evaluators and end user testers, with data presented as medians/range given the small sample size. The summative SUS score was calculated as per Sauro's methodology[43].

Ethical Issues and Limitations

A Research Ethics Board Amendment application for this study was approved by the Hamilton Integrated Research Ethics Board (HiREB, approval #10910). An amendment pertaining to changes to methodology to allow virtual testing in the context of the COVID-19 pandemic was also approved. A copy of the REB approval letter can be found in Appendix H.

All consent forms, case report forms, completed questionaries, screen recordings, study data, and other sensitive information were stored on an offline, password protected, encrypted drive in a locked cabinet within the Thesis supervisor's research unit for security and confidentiality purposes.

Results

Heuristic Evaluation

Three heuristic evaluators participated: a user interface (UI) expert, a user experience UX) expert, and a peri-operative anticoagulation management expert. Each evaluator participated in one evaluation session. The session duration was 81 minutes for the anticoagulation expert, 57 minutes for the usability expert, and 47 minutes for the user experience expert. The number of issues by category and evaluator is presented in Table 4. A total of 75 usability issues were identified by the evaluators. After aggregation and debriefing, 51 unique issues were agreed upon by the evaluators. 41.1% of issues were categorized as “Match between system and real world”, and 19.6% were categorized under “Aesthetic and minimalist design”, with 39.3% falling into the other categories (Table 2). 45% of the issues were designated a ‘3’ or ‘4’ on the severity scale which is translated to “Major usability problem, important to fix, should be given priority” or “Usability catastrophe, imperative to fix before application is released” respectively (Appendix J). The Thrombo-Link app was then revised as described in Methods in preparation for end user testing.

Table 2. Heuristic and Number of Issues Found

	# of Issues Found (%)			
Heuristic	**Content Expert**	**UX Expert**	**UI Expert**	**Aggregated**
Visibility of System Status	0 (0%)	2 (6.9%)	1 (4.0%)	2 (3.9%)
Match between System and Real World	15(71.4%)	13 (44.8%)	8 (32.0%)	21 (41.1%)
User Control and Freedom	2 (9.5%)	4 (13.8%)	1 (4.0%)	6 (11.8%)
Error Prevention	0 (0%)	4 (13.8%)	5 (20.0%)	6 (11.8%)
Recognition rather than recall	1(4.8%)	0 (0%)	0 (0%)	1 (2.0%)
Flexibility and efficiency of use	0 (0%)	0 (0%)	1 (4.0%)	1 (2.0%)
Aesthetic and minimalist design	0 (0%)	5 (17.2%)	8 (32.0%)	10 (19.6%)
Consistency and Standards	3 (14.3%)	1 (3.4%)	1 (4.0%)	4 (7.8%)
Total	21(100%)	29 (100%)	25 (100%)	51 (100%)

After consensus among evaluators was reached a total of 51 unique issues were identified with their respective severity rating. Each issue was addressed in order of severity over 8 weeks with 51 tickets filed through Jira Software. After all 51 issues were resolved, a single iteration of the Thrombo-Link app was made. This iteration then underwent a thorough review and was approved by evaluators before moving onto end user testing.

Presented here are examples of solutions to issues found in heuristic testing (with a severity score of 4):

Issue 1 – Page 9 missing Mg/day input for medications. Solution – Insert text box for medication dosage.

Issue 2 – some back buttons not working. Solution – Ensured all back buttons were functional.

Issue 3 – Procedure dropdown menu confusing and cluttered. Solution – Created text box for free text input of procedure.

Issue 4 – Page 3 LMWH options showing even when LMWH is not selected. Solution – Inserted clause that only shows LMWH menu if LMWH is selected by user.

Issue 5 – Final Report not showing. Solution – Final Report created as a text dictation that will be inputted into medical record.

Screenshots of the app can be found in Appendix K.

End User Usability Testing

Of the one clerk, two physicians, and four nurses (7 staff total) that work in the Hamilton General Hospital perioperative anticoagulation clinic, one clerk, one physician, and three nurses volunteered to be a part of the study (n=5, 71%). Demographic data of end user testers are given in Table 3. There was a preponderance of female end user testers (80%), and all participants had college diploma or higher level of educational attainment. The UTAUT-based Relationship with Mobile Technology survey indicated a high level of acceptance of mobile technology, with medians of 4-5 (on a 5-point Likert scale, with 1 indicating “strongly disagree” and 5 indicating “strongly agree”) in 6 of 8 domains (Table 4)[6].

Table 3. Demographic information of End User Usability Participants

Characteristic	n (%)
Sex	
Male	1(20%)
Female	4(80%)
Age (Range 33-59)	
Under 50	2(40%)
Over 50	3(60%)
Median Participant Age: 56	
Occupation	
RN	3(60%)
Clerk	1(20%)
Physician	1(20%)
Education	
Undergraduate / College	4(80%)
Graduate/ Professional Degree	1(20%)

Table 4. Results from Pre-Study Survey (UTAUT: Relationship with Mobile Technology[6])

Question	Median Answer (Range)
Performance Expectancy	
1. I find mobile Internet useful in my daily life	5 (5)
2. Using mobile Internet helps me accomplish things more quickly.	5 (4-5)
3. Using mobile Internet increases my productivity.	5 (4-5)
Effort Expectancy	
1. Learning how to use mobile Internet is easy for me.	5 (4-5)
2. My interaction with mobile Internet is clear and understandable.	4 (4-5)
3. I find mobile Internet easy to use.	5 (4-5)
4. It is easy for me to become skillful at using mobile Internet.	4 (4-5)
Social Influence	
1. People who are important to me think that I should use mobile Internet.	5 (1-5)
2. People who influence my behavior think that I should use mobile Internet.	4 (1-5)
3. People whose opinions that I value prefer that I use mobile Internet.	5 (1-5)
Facilitating Conditions	
1. I have the resources necessary to use mobile Internet.	5 (4-5)
2. I have the knowledge necessary to use mobile Internet.	5 (4-5)
3. Mobile Internet is compatible with other technologies I use.	5 (3-5)
4. I can get help from others when I have difficulties using mobile Internet.	5 (4-5)
Hedonic Motivation	
1. Using mobile Internet is fun.	5 (3-5)
2. Using mobile Internet is enjoyable.	4 (3-5)
3. Using mobile Internet is very entertaining.	5 (2-5)
Habit	
1. The use of mobile Internet has become a habit for me.	4 (3-5)
2. I am addicted to using mobile Internet.	3 (2-5)
3. I must use mobile Internet.	5 (4-5)

Behavioral Intention	5 (4-5)
1. I intend to continue using mobile Internet in the future.	4 (4-5)
2. I will always try to use mobile Internet in my daily life.	5 (4-5)
3. I plan to continue to use mobile Internet frequently.	
Use	
Please choose your usage frequency for each of the following: frequency ranges from "never" (0) to "many times per day"(5) – Likert scale	
1. SMS	5 (4-5)
2. MMS	4 (3-5)
3. Ringtone and logo download	1 (1)
4. Java games	1 (1-3)
5. Browse websites	4 (4-5)
6. Mobile email	5 (3-5)

The median (range) duration of the sessions was 32 minutes (22-43 minutes range). During the think-aloud, participants identified issues in the app as demonstrated by the following quotes:

Participant 1:

"The check boxes for answers are very far from the text, I'm losing track of which option I picked"

Participant 2:

"The DVT Type selection page is coming up even though I did not select the DVT option in the previous page"

Participant 2:

"The app doesn't allow me to type in the type of Cancer the patient has in the textbox"

Participant 3:

"Why is the app asking me what type of heart valve the patient has when I didn't select heart valve replacement as a pre-existing condition"

Participant 3:

"This page (11) asks if the patient has experienced any of the following conditions. There should be an option for none of the above as some patients do not have any of these pre-existing conditions"

Participant 4:

"The question 'physician name' is unclear, are we supposed to type in the referring physician, family physician, or the surgeon?"

Participant 4:

"If I already picked the type of anticoagulant the patient is taking, why does that app ask if the patient is on warfarin or not, it's confusing"

After transcription of the recorded sessions, seven discrete issues were identified. The System Usability Scale (SUS)[24] was administered after the end user test and the responses are shown below in Table 5. As shown, needing to learn a lot before using the app, app complexity and cumbersome use of the application all had a median answer of 1 (Strongly Disagree) respectively. Perceived ease of use and function integration were scored a median of 5 (Strongly

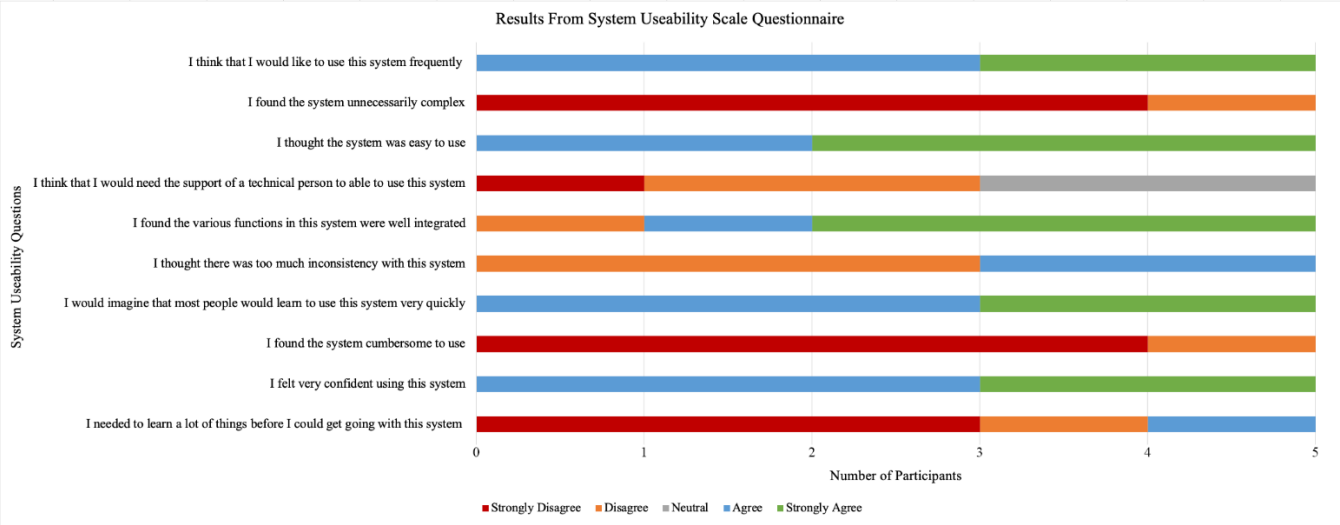
Agree). The summative SUS score had a mean of 82 with a standard deviation of +\- 11.7 and a range of 65-95.

Table 5. Results from System Usability Scale[24] for End User Testing

Question	Median Score (Range)	Mean Scores (SD)
1. I think that I would like to use this system frequently	4 (4-5)	4.4 (0.55)
2. I found the system unnecessarily complex	1 (1-2)	1.2 (0.45)
3. I thought the system was easy to use	5 (4-5)	4.6 (0.55)
4. I think that I would need the support of a technical person to able to use this system	2 (1-3)	2.2 (0.84)
5. I found the various functions in this system were well integrated	5 (2-5)	4.2 (1.30)
6. I thought there was too much inconsistency with this system	2 (2-4)	2.8 (1.10)
7. I would imagine that most people would learn to use this system very quickly	4 (4-5)	4.4 (0.55)
8. I found the system cumbersome to use	1 (1-2)	1.2 (0.45)
9. I felt very confident using this system	4 (4-5)	4.4 (0.55)
10. I needed to learn a lot of things before I could get going with this system	1 (1-4)	1.8 (1.30)

SUS score range 1 (strongly disagree) to 5 (strongly agree).

Figure 1. Results from System Usability Scale Questionnaire



Discussion

This study found that the Nielsen's heuristics could be used to identify severe and non-severe usability issues in a perioperative anticoagulation management CDSS. End user testing identified additional usability issues. An unanticipated finding was that the usability testing could be conducted at a distance as a result of the COVID-19 restrictions on research during the pandemic.

Heuristic Evaluation

During the heuristic evaluation of the Thrombo-Link application, 51 usability constraints from 8 heuristics were identified by the team of evaluators. The highest number of issues arose from the "match between the system and the real world" category with 21 issues being observed, with 15 being identified by the content expert alone. Moreover, 10 issues were identified with the aesthetic and minimalist design of the application. The fact that the majority of issues were detected within these two heuristic categories demonstrates how vital a simple, yet functional design is when developing an application that is intended for use by healthcare professionals. It was evident that using layman's terms is crucial when developing such applications as not all users will understand the jargon of medical terminology. This may be explained by the fact that two of the three evaluators were not healthcare professionals and may not understand the complex medical terminology within the app. User control and freedom, as well as error prevention, were found to be important heuristics when evaluating Thrombo-Link. Each of these heuristics had 6 notable usability constraints that required rectification before end user testing could begin. The usability issues detected in the error prevention category could have resulted in missing information which would have altered the output of the app algorithm. To rectify this

potential issue, the app was developed as such that the user could not skip any pages without completing all elements of the form. This presented us with another issue when patients do not have a certain condition or users do not have an answer for the question asked within the app. To rectify this, a “not sure” or “not applicable” option was placed on every screen, allowing users to continue filling out the application questionnaire, even if they did not have answers, but still ensuring completeness of data. Subsequently, when completing the form within the application, integrated flags were developed to let users know when “not sure” or “not applicable” was selected so that the healthcare professional could follow up on the specific question.

Furthermore, from the heuristic evaluation, it was evident that the Thrombo-Link application had issues with consistency and standards. Due to the intricate nature of peri-operative anticoagulation medication management, the software developers often misspelled medical terminology. An example of this is the common mistake of misspelling the word ‘disease’. Although this is a harmless spelling mistake, the importance of professionalism, consistency, and standards are stressed when implementing such a complex clinical decision support tool.

No issues were discovered in the “help users recognize, diagnose, and recover from errors” or “help and documentation” categories. This can be explained by the Thrombo-Link app being a multiple choice and fill in the blank type of application. Since the app has a unidirectional design, there are no complex menus required within the app and users are less likely to encounter errors or require help during app navigation.

Of the issues found by the content expert, a greater proportion were classified in the category of “Match between system and real world” than for the other evaluators. In contrast, the content expert did not detect any “Aesthetic and minimalist design” or “Error prevention” issues,

but 10 and 6 unique issues respectively were detected by the other two evaluators in these categories. It is possible that heuristic evaluation done by a content expert (who is not also a user experience expert) as opposed to a user experience expert may reveal different types of issues using Nielsen's heuristic evaluation. When originally developed, Nielsen's heuristic evaluation was envisioned to be conducted by software developers[20]. Several studies describe heuristic usability testing of CDSS. In two of the studies the heuristic evaluators were all usability experts, (McCulloh 2018[40] used human factors specialist; Peleg[41] used usability experts.) In one study (Yuan[42]), four evaluators participated, with one being a user experience expert, and three being content domain experts. This study does not describe differences in categories of issues detected by the various evaluators.

The inclusion of data on severity in the heuristic evaluation was useful as it allowed for the prioritization of which usability issues needed to be rectified immediately, while others were backlogged within the development cycle. Many of the level 4 severity issues that were identified had a direct connection with the knowledge-based algorithm of the application and its functionality. These were design issues that would render the application unusable or at least very frustrating for the end user. An example of this was an issue where the 'back' button was not functional on every page/screen of the application. This could become a safety issue as a user is not able to go back and change an unintended selection which may lead to the CDSS making an inaccurate or dangerous recommendation. Although users were able to move forward through the application, if they made a mistake or wanted to change a previous answer, they were unable to as the back buttons in the application were not functional.

Overall, the application of Nielsen's heuristic evaluation method was able to identify issues to resolve during the development of the app during this study. The 8 heuristic categories

were applicable to the Thrombo-Link app and aided in the iterative design process by identifying both major and minor issues within the UI.

End User Testing

The pre-study questionnaire provided a clear picture of whether or not the participants use the internet, mobile technology, and integrated applications. It was seen that the clinic staff use mobile technology on a daily basis and value its functionally. Moreover, participants agreed that they must use mobile internet/technology. Both results indicate a high level of familiarity. The pre-study questions of "I have the necessary resources to use mobile internet" and "I have the knowledge required to use mobile internet" suggest that the clinical staff possess the resources and knowledge to use mobile technology especially in a healthcare setting. This may limit the generalizability of our findings, as end users with less familiarity may identify different usability issues.

The mean SUS score of the Thrombo-Link app which was revised after heuristic testing alone was at the 85th percentile when compared to 500 other systems[43]. Although the sample size was small, usability concerns were noted in the following domains: inconsistency, integration, and need for training before using the product. The usability of the app is likely to be even further improved after development based on end-user testing.

It is evident that during usability testing, the heuristic evaluators tend to focus on making the application functional, while the end users tend to focus on performance and efficiency of the application[44]. This is further evident when comparing the heuristic evaluator comments to the end user comments; where the heuristic evaluators focus more on the UI, UX, and technical information while the end users focused on the content of the application including making

selections or inputs more specific to gather the information they require. Overall, this study found that both heuristic evaluation and end user testing identified major issues with the Thrombo-Link app. It also supports the value of employing both heuristic evaluation and end user testing to ensure that all usability issues are identified while also maintaining a user centered design approach. These methodologies are inexpensive and can be applied with ease to ensure novel health technologies are adopted at the clinical level.

Limitations and Strengths

We did not inspect the app for usability using cognitive walkthrough methodology, and some authors suggest that both cognitive walkthrough and heuristic testing should be employed in usability inspection[14]. In a study of a hospital information system comparing heuristic evaluation with cognitive walkthrough, the two methodologies revealed a similar number of issues[45]. This finding is consistent with older literature comparing heuristic evaluation and cognitive walkthroughs outside of the medical context[46]. In the study of a hospital information system, there was a higher proportion of issues related to "learnability" detected by cognitive walkthroughs, and a higher proportion related to "satisfaction" detected by heuristic testing. The authors hypothesize that heuristic testing may be more appropriate for products designed for end users with a high degree of familiarity with the technology. We did find a high level of familiarity with mobile technology in the clinic staff.

Another limitation is the low number of participants involved. Although cost effective, heuristic evaluation utilizing a small number of participants may not detect all issues. This study incorporated three experts with varying domains of expertise. With this small of a sample size, it could not be determined whether saturation was reached in issue detection. However, there were

a relatively small number of issues detected during end-user testing compared to the number of issues detected during heuristic testing, and summative assessment of usability suggested that heuristic testing with just three purposively selected evaluators was able to detect most issues. Because the end users in this study had relatively high expectations and familiarity with mobile technology, the results may not be applicable to end users with less experience with mobile technology. Finally, this mixed method approach only tests the usability of the app and does not explore the validity of its use. The knowledge-based algorithm is not tested nor was real patient data used during this study.

A major challenge in the conduct of this study was the global COVID-19 pandemic that started during the later months of 2019 and continued through the year 2021. It was not possible to conduct an in-person study due to the social and physical distancing rules that were implemented by local governments and research ethics boards. Although amendments to the protocol were required, we were able to conduct the usability sessions over video conference. This introduced a limitation as there was a lack of face-to-face interactions. Face to face interactions are important because of the significance of one on one communication and body language to such a usability study[47]. However, the use of video conference technology mitigated this limitation by at least allowing visualization of the facial expressions of both the end users and study personnel.

Despite the study limitations there are several strengths that are important to note. Since the heuristic experts already had access to the technology, there were no major costs related to the study other than the procurement of new iPads that were provided for the clinic staff. A high proportion of HGH clinic staff were involved, thus the population of interest was well represented during the end user testing.

Conclusion and Future Directions

This study found that usability testing using Nielsen's heuristics followed by iterative development and end user testing using walk-through and think aloud methodologies was able to identify usability issues in an app for a perioperative management of anticoagulation clinic.

This project explored the usability and acceptance of the Thrombo-Link app. In the context of the UASAD model the next steps to this study are to continue user testing until all usability issues are identified and addressed, then validate the application algorithm, then perform further usability testing using clinical simulation and naturalistic settings[14]. A longer-term goal is to fully integrate the CDSS into the electronic medical record, allowing automation of data extraction from and documentation output into the patient's medical record. Further study into the categories of usability issues detected by content domain experts vs. usability experts could improve the effectiveness of heuristic testing of CDSS. More precise estimation of the relationship between the number of heuristic testers and the proportion of total issues detected in the context of CDSS usability testing could help improve efficiency of usability testing in future.

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Appendix A: Telephone Script

Script for user testing:

Welcome and Purpose

Thank you so much for coming in today. I wanted to give you a little information about what you will be looking at and give you time to ask any questions you might have before we get started.

Today we are asking you to serve as an evaluator of a mobile application that can be used to directly enter information and to complete a set of tasks. Our goal is to see how easy or difficult you find the site to use.

Test Facilitator's Role

I am here to record your reactions and comments about the app you will review.

During this session, I would like you to think aloud as you work to complete the tasks. I will not be able to offer any suggestions or hints, but from time to time, I may ask you to clarify what you have said or ask you for information on what you were looking for or what you expect to have happen.

Test Participant's Role

- Today I am going to be asking you to perform a few tasks on the app and tell me how easy or difficult it was to do. These activities are all about how easy we have made it for people to use the site.
- There is no right or wrong answer. If you have any questions, comments or areas of confusion while you are working, please let me know.
- If you ever feel that you are lost or cannot complete a task with the information that you have been given, please let me know. I will ask you what you might do in a real-world setting and then either put you on the right track or move you on to the next scenario.
- As you use the app, please do so as you would at home or your office. I would ask that you try to work through the tasks based on what you see on screen.
- We will be recording this session for reference if needed. We are capturing your voice and what you see on the screen. Your name will not be associated or reported with data or findings from this evaluation.
- I may ask you other questions as we go and we will have wrap up questions at the end.

Do you have any questions before we begin?

Appendix B: Thrombo-Link UT Protocol

Protocol: Thrombo-Link UT - Usability testing and iterative design of an electronic program to aid in periprocedural management of antithrombotic medication.

BACKGROUND

Patients taking anticoagulants for indications including stroke prevention in atrial fibrillation, secondary prevention of venous thromboembolism, and prevention of prosthetic heart valve thrombosis commonly require interruption of anticoagulation before undergoing invasive procedures; one in six patients taking warfarin for atrial fibrillation will require such an interruption every year.[1,2] The peri-operative period is of particular risk for patients taking anticoagulants, with nearly 1% of patients experiencing a thrombotic event, and over 4% experiencing major bleeding.[3] Although a major study has clarified the optimal perioperative management of warfarin for patients with low or moderate thromboembolic risk atrial fibrillation,[4] there is considerable uncertainty about how to manage patients at higher risk, with other indications for anticoagulation, or who are using other anticoagulants.

The Bridging Clinic
At the Hamilton General Hospital, the Peri-operative Management of Anticoagulation ("Bridging") Clinic assesses patients requiring procedures and provides recommendations on how to manage anticoagulants around the time of the procedure. The clinic runs 4 days a week, and in 2017, 1289 patients were assessed and given recommendations. The majority of patients are taking anticoagulation for atrial fibrillation, but up to 15% are being anticoagulated for venous thrombosis. The Bridging Clinic provides a valuable service to patients in the region, but an identified limitation has been a reliance on paper-based documentation. Transitioning to an electronic format for documentation has the potential to expedite patient flow through the clinic, reduce time spent by clinic staff on "low-value" tasks such as copying data onto written forms, and can improve the quality and timeliness of documentation provided to patients and referring physicians.

Current paper-based clinic flow
Before the patient is seen, a referral is received from the surgeon and a paper chart is created. The patient appointment is scheduled using the hospital-wide electronic scheduling system, and the patient is informed. When the patient arrives in clinic, they check in and are given a paper form to fill while waiting to be seen by the nurse. This form gathers information on the indication for anticoagulation, risk factors for thromboembolism and bleeding, and the dose and timing of the anticoagulant. The patient is then seen by a nurse who reviews the referral and the form filled by the patient, gathers further information on recent bloodwork and patient weight, and completes another paper form. The nurse then discusses the case with the bridging physician, who produces the recommendation for interruption and resumption of anticoagulation. This recommendation is then transcribed onto a paper-based calendar, and copies are made for the patient, the referring physician, the clinic chart, and for the inpatient Thrombosis nurses who

may need to see the patient while in hospital for the surgery. Finally, the physician dictates a note onto the hospital electronic medical record (EMR).

Potential for improvement with a digital system

Although this system works well overall, there are several opportunities for improvement in switching to a digital format. In general, digital documents offer improvements over paper in legibility, accessibility over distance, security, space requirements, and also allow automation of some data entry. Specific to the Bridging Clinic, digitization has the potential to improve efficiency by allowing forms to be automatically filled with previously entered data, and by automating the selection and preliminary filling of template recommendation documents. This can reduce time spent by the patient, nurses, and administrative staff in filling out paper documents, which can liberate time for higher-value tasks such as counseling and instructing patients. Digitization can also reduce the time spent by the physician dictating the recommendations, which can result in the recommendations being more quickly available on the hospital-wide EMR. Furthermore, the increased efficiency can allow more information to be included in the note on the hospital EMR, improving communication with other services and obviating the need for some of the paper copies. Although adherence to guidelines and standards of practice is likely to be high in our clinic, the digital system could improve adherence by incorporating current recommendations, and would also make it easier to assess the quality of our service.

App development to-date

We have developed an app that can be run on iOS tablets, with informal input from bridging clinic physicians, nurses, and clerical staff. The app is now ready for formal usability testing. Usability will be tested in 4 stages. Once usability testing is complete, the final version of the app will be piloted to determine effects on staff member time and workflow, and user satisfaction. This would be the subject of a separate REB application. This software may be of interest to other clinics that manage antithrombotic medications around the time of invasive procedures.

OBJECTIVES

Overall Objective:

To reduce workload of tasks such as recopying of information by hand or by dictation.

Specific Objective:

To improve the usability of our clinical app through cycles of usability testing.

STUDY DESIGN

Prospective usability study in which participants are assigned tasks to complete with the ThromboLink prototype application, their performance is monitored, and feedback is requested from the participants.

Study setting:

This is a single centre study performed at the Hamilton General Hospital.

Study population:

The study population will be derived from the following groups:

1. Clinic staff (nurses, clerical staff, physicians)
2. Patients and their caregivers/family members (the ‘Patient Group’)

Inclusion criteria:

Membership of one of the above groups.

Exclusion criteria

1. Inability to participate via Internet;
2. Inability or unwillingness to provide informed consent.

METHODS

User testing will consist of 4 stages, with iterative improvement at each stage. The first stage is Technical Walkthrough. 3 patients and 3 nurses will navigate through the app with the goal of evaluating the technical function of the app. The tablet will be used to capture screen and voice recordings to identify technical glitches and faults in flow. These will be rectified before proceeding to the next stage.

The second stage is Cognitive Walkthrough. Participants will use Concurrent Think Aloud Methodology, in which they continuously narrate their thoughts as they navigate the app. Screen and voice capture will again be used. The purpose of this stage is to evaluate the flow and understandability of the app, and 5 patients and 4 nurses will participate.

The third stage is Formative Evaluation, and uses similar methodology as Cognitive Walkthrough, except that participants are asked to complete predefined tasks (e.g. "Please fill out this form," "Please set up a new patient file," etc.) Physician input will also be sought at this stage to ensure appropriate information is captured and included in an automatically produced draft dictation.

The fourth stage is Summative Evaluation. 10 patients, 4 nurses, and 2 physicians will participate using recorded Concurrent Think Aloud Methodology. In this stage, participants will be asked to simulate using the app as they would in "real life". Besides providing qualitative feedback, participants will then evaluate the app using the System Usability Scale (Appendix 3).

Before and after every stage, there will be a debriefing with the clinic personnel, and iterative improvement to the app will be undertaken.

Recruitment

Clinic staff who have expressed interest in learning more about the study will be approached by research personnel (not a physician, to avoid coercion) via telephone. Clinic staff that indicate that they would like to participate will then undergo the information and consent procedure, and those that consent will be enrolled and scheduled for user testing. This process will take place via telephone and/or Internet.

Clinic patients and/or their family members and caregivers will be asked by clinic staff if they are interested in learning more about the study. Those that agree will undergo the information and consent procedure, and those that consent will be enrolled and scheduled for user testing. This process will occur via telephone and/or Internet.

Compensation

Each participant will receive $15 in the form of an electronic voucher (Amazon gift card) for each session that is completed or partially completed, in order to compensate for costs such as Internet usage.

Preliminary Evaluations

Method 1: Technical walkthrough

Objective: To evaluate the technical function of the app.
Participants: Clinic staff and clinic patients and/or their family members and caregivers.
Process: The technical walkthrough will be completed on iPads. The devices will be loaded with the ThromboLink app and screen/voice capture technology.
The participants will receive an overview of the usability test procedure, equipment, and software and the objectives of the technical walkthrough. They will complete a consent form. Participants will be asked to navigate through the whole app and to provide feedback on issues regarding the technical aspects to the app (e.g., flow of screens, forward and back buttons, desired functions, improved language in the app, etc.). Data collected will include functional concerns about navigation and presentation.
Tools: iPad with the app loaded and a screen capture app that will record activity on the screen and voice.
Data: Field notes by the observer; voice and screen capture of the participant which will be used to assess navigation errors and recommendations for better flow, language of instructions, and desired functionalities.
Location: via videoconference.
Time: Approximately 30 minutes/user.
Sample size: 5 users from clinical staff (including at least one nurse, one physician, and one clerical staff) and 5 members of the Patient Group. This sample size should identify at least 75% of the issues. [5]

Method 2: Cognitive walkthrough

After completing the technical walkthroughs, our developer will incorporate the feedback from the participants and improve the app to meet the needs of research staff and research participants. The improved app will then be used for Cognitive walkthrough testing.
Objective: To evaluate the flow and understandability of the app.
Participants: Members of the clinic staff, and Patient Group.
Process: The cognitive walkthrough will be completed on iPads loaded with the ThromboLink app and a screen/voice capture app.
The participants will receive an overview of the usability test procedure, equipment, and software and the objectives of the cognitive walkthrough. They will complete a consent form and a demographic questionnaire. The test facilitator will take them through a Concurrent Think Aloud exercise. Think Aloud allows us to understand participants' thoughts as they interact with the app by having them talk through their thought processes while they complete the tasks. The goal is to encourage participants to keep up a running stream of consciousness. Participants will briefly be trained on Think Aloud by asking them to walk through their childhood home recounting the number of windows in each room as they 'walk' though the house. This allows for the observer and facilitator to understand the logic process of users.
For the Clinic Staff, our facilitator will then lead them through the app: signing in, loading a fictitious patient, completing the staff component of the app, producing and approving a recommendation, and approving the dictated note. For members of the Patient Group, they will be led through the following processes: entering the information requested by the app, viewing the recommendation produced.

The cognitive walkthrough will be conducted either in person in an office in the research institute or virtually via videoconference. Participants will navigate the whole app and be prompted to answer these queries while they complete the tasks:

- Will the user know what to do at this step?
- If the user does the right thing, will they know they are progressing through the app?
- Feedback on user interface and performance challenges
- Evaluate heuristic principles such as language, aesthetics, simplicity, predictability, accuracy, precision of the app

Tools: iPads loaded with ThromboLink, a screen capture app, and voice recorder for Think Aloud (where the participant talks through their actions and thought process aloud).
Data: Notes on areas of concern regarding flow and steps at which the design could be improved to help the user navigate the app. Notes based on the voice recording of think aloud from the sessions.
Location: virtually via videoconference.
Time: Approximately 30 minutes/user.
Sample size: 5 users per user group should identify at least 75% of the issues. [5]

User Testing

Method 1: Formative evaluation

The functional and cognitive walkthroughs help guide the development and refinement of the app to meet the needs of the users. The formative evaluation ensures that users can navigate through the app easily and complete the various tasks.
Objective: Evaluate the performance of the app while users complete predefined tasks. Tasks will include: signing in, entering information, reviewing and approving recommendations, reviewing and approving dictated notes.
Participants: Clinic staff and Patient Group.
Process: Participants will provide consent and complete a pre-test interview to capture demographic data (age, occupation) and baseline information on their experience with technology. The test facilitator will take them through a Concurrent Think Aloud exercise. Think aloud allows us to understand participants' thoughts as they interact with the app by having them talk through their thought processes while they complete the tasks. The goal is to encourage participants to keep up a running stream of consciousness. The facilitator will provide an overview of the app and provide directed tasks, in the form of scenarios, to complete. We will capture screen and voice recordings of the session. The participants will then complete a post-task debriefing interview including the System Usability Scale to get their overall thoughts on the app.
Participants will be led through a series of scenarios which they would normally encounter as they proceed through a clinic visit. Through each of the scenarios, they will use the app and use think aloud to explain their rationale and thought process.
For Clinic staff: the scenarios will include simulated patients with a range of thrombotic risk, antithrombotic drugs, and procedures.
Predefined tasks that clinic staff will complete include:

- Sign in
- Load a patient

- Enter in information for a simulated patient
- Review, amend, and approve a recommendation
- Review, amend, and approve dictated note

For patients/caregivers: they will enter dummy data representing a simulated patient, to maintain privacy of their health information. The simulated patients will include a range of thrombotic risk, antithrombotic drugs, and procedures.
Predefined tasks that patients/caregivers will complete include:

- Complete the visit questionnaire
- Review recommendations

The debriefing interview questions will be open-ended and ask the user about their perceptions of the app. They will also complete the System Usability Scale, 10 statements, on a 5-point Likert scale (strongly disagree to strongly agree):

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

Tools: iPads ThromboLink app loaded, a screen/voice capture app.
Data: Notes on areas of concern regarding flow and steps at which the design could be improved to help the user navigate the app. Notes based on the voice recording of think aloud from the sessions. Demographic data, pre- and post-interview data, System Usability Scale scores.
Location: virtually via videoconference.
Time: Approximately 60 minutes/user.
Outcomes: recommendations to improve the app.
Sample size, number of cycles: We will recruit 3 clinic staff and 3 past research participants for 2 cycles of testing (6 research assistants and 6 participants). Between each cycle, our app developer will make iterative improvements to the app based on the feedback received in the previous cycle.

Method 2: Summative evaluation

Objective:

Testing the system before launch. Users will be asked to navigate the app without assistance while using Concurrent Think Aloud. Any issues with the interface and navigation will be

noted. This evaluation replicates 'real-life' interaction with the app, where the user is not led through the app. We will be evaluating the participant's behavior, e.g., success at navigating the steps, time to complete tasks, errors, frustration. [6]

Participants: Research staff from PHRI and previous participants of clinical research studies.

Process: Ideally for a summative usability evaluation, the participant engages with the technology independently. Participants will be recruited from the Bridging Clinic. They will provide consent and complete a pre-test interview to capture demographic data and baseline information on their experience with technology. The facilitator will provide an overview of the app and then either leave the room and observe the participant remotely (in-person) or sit quietly (videoconference) to observe the participant work through the app. We will capture screen and voice recordings of the session. The participants will then complete a post-task debriefing interview to get their overall thoughts on the app and the System Usability Scale.

Tools: iPad with the app loaded and screen/voice capture for think aloud methodology.

Data: Notes from observation, demographic data, pre- and post-interview data. From the screen capture, we will quantify time to complete the various tasks in the app. We will note start and end time for each task based on the screen capture recordings to get accurate measures of time on task. A priori, we will define criteria for task success, and evaluate if the participant is successful on the task.

Location: via videoconference.

Time: Approximately 60 minutes/user.

Outcomes: Use errors, successful completion of tasks, incomplete tasks, and time on task.

Sample size: 20-25 participants to analyze data on time to complete tasks. [6,7] Wiklund (2012) recommends ≥15 from each user group or ≥25 if you have 1 user group.

References:

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Healthcare Technologies. E-Health and Telemedicine: Concepts, Methodologies, Tools, and Applications. Hershey, PA: IGI Global; 2016. p. 429–443.
[6] Travis D. 2 kinds of usability test [Internet]. 2012 [cited 2017 Jul 28].
[7] Wiklund M, Kendler J, Strochlic A. Usability Testing of Medical Devices. Second Edi. Boca Raton, FL: CRC Press; 2015.

Appendix C: Thrombo-Link UT Informed Consent Form

PARTICIPANT INFORMATION & CONSENT FORM

Study Title: Usability testing and iterative design of an electronic program to aid in periprocedural management of antithrombotic medication. (Thrombo-Link UT)

Locally Responsible Principal Investigator:

- Dr. Vinai Bhagirath, Dept. of Medicine, McMaster University

Co-Investigators:

- Mr.Fady Said, Dept. of Health Sciences, McMaster University
- Dr. Cynthia Lokker, Dept. of Health Evidence and Impact, McMaster University

Funding Source:

Pfizer Canada unrestricted educational grant

Invitation to participate in research:

- You are invited to participate in this study conducted by Dr. Vinai Bhagirath from McMaster University.
- You are eligible to participate because you are involved either as a patient, caregiver of a patient, or staff member of the Perioperative Anticoagulation Clinic (Bridging Clinic) and have expressed interest in evaluating a mobile application to collect clinic data.
- To decide whether or not you want to be a part of this study, you should understand what is involved and the potential risks and benefits. This form gives detailed information about the study, which will be discussed with you.
- Once you understand the study, you will be asked to sign this form if you wish to participate. Please take your time to make your decision.
- Your participation is voluntary. If you agree to participate, you may withdraw from the study at any time without any penalty.
- Choosing not to participate in this study will in no way affect your access to health services or health information.

Why is this study being done?

- Involving users in the design of formats and strategies such as technology to communicate health information can make the technologies more relevant and usable for users.
- We want to know if the mobile application we are developing is easy to use and understand by the people we are designing it for.
- We need the help of clinic staff and patients like you to help us evaluate the application.

How many participants will be in this study?

- A total of 66 research participants will be enrolled in the various stages of this study. They will participate in individual sessions.

What will my responsibilities be if I decide to participate?

- After consenting to participate in this study, you will be asked to attend one or more sessions via videoconference. In these sessions, you will evaluate our mobile application. You will be using an Apple iPad that we will provide. This device will record and capture your voice and activities on the screen as you make your way through tasks described by our facilitator.
- The aim of the sessions is to understand if the application is easy to use and navigate. Your feedback during the sessions will be used to improve the application.
- These sessions will take place remotely while participants are in a safe and comfortable location. They will last approximately 30 minutes to 1 hour.
- If you are asked to do more than one session, you can decide how many sessions to participate in.

Are there any risks involved in this study?

- It is unlikely there will be any risks or harms from participating in this study.
- Remember you are free to stop participating at any time.
- The information you share will be kept confidential as described below. See '*What will happen to my personal information?'*.

What are the benefits to me and to society from participating in this study?

- We cannot promise any personal benefits to you from your participation in this study.
- Possible benefits include:
    - feeling good that you are contributing to knowledge that will potentially help others in the future
    - making it easier for future users of our application to use and understand the flow and data gathering.
    - contributing to science that may improve informational support for clinics.

Will I be paid to participate in this study?

- Yes. To compensate you for your time and cost of Internet data and phone usage, you will receive $15 for every session you attend.

Who will own the intellectual property produced in this study?

- McMaster University and the study investigators will own any intellectual property (such as copyright on the software) produced as a result of this study. The intellectual property will not belong to you.

Will there be any costs to me in this study?

- There may be costs associated with use of Internet data and telephone, for which you will be compensated $15 per study session.

What will happen to my personal information?

- We will not collect any identifying information about you, although we will be recording audio of your comments during the session, and may use direct quotes when publishing the results.
- We will use identification numbers instead of your name to identify you and other participants in our files.
- During the study, the data you provide (recordings and questionnaires) will be stored on a computer in the Population Health Research Unit at Hamilton General Hospital which is secured against viruses and hacking.
- We will omit information that could identify you from recordings, transcripts and study reports.
- We will keep study data for 15 years, after which it will be securely destroyed.

Can participation end early?

- You are free to withdraw from the study at any point, for any reason, without consequence to you.
- Your decision to withdraw will not affect your access to services.
- To withdraw, notify either the contact person below, or one of the researchers, as soon as possible. This can be during a session, by phone, or by email. See "*Whom should I contact?*".
- If data have already been collected during a session before you withdraw, you should indicate whether you wish to have any of your information included or excluded from the study.

Whom should I contact if I have questions about this study?

Dr. Vinai Bhagirath
6th Fl. M-Section
Hamilton General Hospital
237 Barton St. E
Hamilton ON L8L 2X2
Ph: 905-521-2100 x40727
bhagiv@mcmaster.ca

CONSENT

Study Title: Usability testing and iterative design of an electronic program to aid in periprocedural management of antithrombotic medication. (Thrombo-Link UT)
Participant agrees with the following statement?

I have fully reviewed the information in this letter. I have had an opportunity to ask questions and all of my questions have been answered to my satisfaction. I agree to participate in this study.

Has Telephone Consent been granted? : Yes /No - Person Obtaining Consent Initials _____

Person obtaining consent:
I have discussed this study in detail with the participant. I believe the participant understands what is involved in this study.

Name, Role in Study	Signature	Date

This study has been reviewed by the Hamilton Integrated Research Ethics Board (HIREB). The HIREB is responsible for ensuring that participants are informed of the risks associated with the research, and that participants are free to decide if participation is right for them. If you have any questions about your rights as a research participant, please call the Office of the REB Chair, HIREB at 905.521.2100 x 42013

Appendix D: Thrombo-Link UT Case Report Form

Case Report Form (CRF) – Usability testing and iterative design of an electronic infrastructure to conduct clinical research through smartphones and tablets - (TL-UT)
Participant ID:

Date of Informed Consent: _/_____/_____
DD MM YEAR

Date of Visit: _____/_____/____
DD MM YEAR

Time of visit: __:____ - ____:___
H MIN H MIN

Stage of Testing

☐ Heuristic Evaluation ☐ End User Cognitive Walkthrough

Inclusion Criteria

Group: ☐ Research Personnel ☐ Research Participant

If Research Personnel – job title/role: _____

Patient Characteristics

Age at baseline visit: _____ years

Sex: ☐ Male ☐ Female

Highest Education Level:

Did not complete High School

☐ High School

☐ College Diploma/Undergraduate Degree

☐ Postgraduate/Professional Degree

Use of mobile internet questionnaire

☐ Survey administered

Appendix E: Heuristic Evaluation User Sheet for Thrombo-Link

Thrombo-Link App Heuristic Evaluation Sheet

Evaluator:
Date:
App: Thrombo-Link App Version:
Device:
OS:

Heuristic	Severity	Issues	Recommendation
1. Visibility of System Status			
2. Match between System and Real World			
3. User Control and Freedom			
4. Consistency and Standards			
5. Error Prevention			
6. Recognition rather than recall			
7. Flexibility and efficiency of use			
8. Aesthetic and minimalist design			
9. Help users recognize, diagnose, and recover from errors (Error Prevention)			
10. Help and Documentation			

Definitions and Documentation

Severity Levels

0. I don't agree that this is a usability issue at all
1. Cosmetic problem only, need not to be fixed as a priority
2. Minor usability problem, fixing is given low priority
3. Major usability problem, important to fix, so should be given high priority
4. Usability catastrophe, imperative to fix before application is released

Heuristic Definition

1. Visibility of System Status
    a. The System should always keep users informed about what is going on, through appropriate feedback within reasonable time

2. Match Between System and Real World
    a. The system should speak the users' language, with words, phrases and concepts familiar to the users, rather than system-oriented terms or jargon. Follow real world conventions, making information appear in a natural and logical order

3. User Control and Freedom
    a. Users often choose system functions by mistake and will need a clearly marked "exit" to leave the unwanted state without having to go through extended dialogue. Support undo and redo

4. Consistency and Standards
    a. Users should not have to wonder whether different words, situations, or actions mean the same thing. Using consistent terms is vital for application success.

5. Error Prevention
    a. Eliminate error-prone conditions or check for them present users with a confirmation option before they commit to the action. Even better than good error messages is a careful design which prevents a problem from occurring in the first place.

6. Recognition rather than recall
    a. 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

7. Flexibility and Efficiency of Use

   a. 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.

8. Aesthetic and Minimalist Design
   a. 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.

9. Help users Recognize, Diagnose, and Recover from Errors
   a. Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

10. Help and Documentation
    a. 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.

Appendix F: Thrombo-Link UT Pre-study Questionnaire[6]

All items are measured using a five-point Likert scale, with the anchors being —strongly disagree (1) and —strongly agree(5).

Performance Expectancy

1. I find mobile Internet useful in my daily life
2. Using mobile Internet helps me accomplish things more quickly.
3. Using mobile Internet increases my productivity.

Effort Expectancy

1. Learning how to use mobile Internet is easy for me.
2. My interaction with mobile Internet is clear and understandable.
3. I find mobile Internet easy to use.
4. It is easy for me to become skillful at using mobile Internet.-

Social Influence

1. People who are important to me think that I should use mobile Internet.
2. People who influence my behavior think that I should use mobile Internet.
3. People whose opinions that I value prefer that I use mobile Internet.

Facilitating Conditions

1. I have the resources necessary to use mobile Internet.
2. I have the knowledge necessary to use mobile Internet.
3. Mobile Internet is compatible with other technologies I use.
4. I can get help from others when I have difficulties using mobile Internet.

Hedonic Motivation

1. Using mobile Internet is fun.
2. Using mobile Internet is enjoyable.
3. Using mobile Internet is very entertaining.

Habit

1. The use of mobile Internet has become a habit for me.
2. I am addicted to using mobile Internet.
3. I must use mobile Internet.

Behavioral Intention

1. I intend to continue using mobile Internet in the future.
2. I will always try to use mobile Internet in my daily life.
3. I plan to continue to use mobile Internet frequently.

Use

Please choose your usage frequency for each of the following: frequency ranges from “never” (0) to “many times per day”(5) – Likert scale

1. SMS
2. MMS
3. Ringtone and logo download
4. Java games
5. Browse websites
6. Mobile email

Appendix G: System Usability Questionnaire

All items are measured using a five-point Likert scale, with the anchors being ―strongly disagree (1) and ―strongly agree (5).

1. I think that I would like to use this system frequently

2. I found the system unnecessarily complex

3. I thought the system was easy to use

4. I think that I would need the support of a technical person to able to use this system

5. I found the various functions in this system were well integrated

6. I thought there was too much inconsistency with this system

7. I would imagine that most people would learn to use this system very quickly

8. I found the system cumbersome to use

9. I felt very confident using this system

10. I needed to learn a lot of things before I could get going with this system

Appendix H: Research Ethics Board Approval

HiREB
Hamilton Integrated Research Ethics Board

Jun-22-2020

Project Number: 10910

Project Title: Thrombo-Link UT - Usability testing and iterative design of an electronic program to aid in periprocedural management of antithrombotic medication.

Student Principal Investigator:

Local Principal Investigator: Dr. Vinai Bhagirath

We have completed our review of your study and are please to issue our final approval. You may now begin your study.

The following documents have been approved on both ethical and scientific grounds:

Document Name	Document Date	Document Version
TL-UT CRF 2020 04 09 v1	Apr-09-2020	1
ThromboLink UT Telephone script 2020 04 21	Apr-21-2020	1
ThromboLink UT Global Budget	Mar-22-2018	1
ThromboLink UT Protocol 2020 06 08	Jun-08-2020	1
ThromboLink UT ICF 2020 06 08	Jun-08-2020	1

The following documents have been acknowledged:

Document Name	Document Date	Document Version
tcps2_core_certificate	Dec-14-2016	1
Response to provisional approval	Jun-08-2020	1

In light of the current COVID-19 pandemic, while this study has been reviewed by HiREB and given final approval status, the actual conduct of the research needs to be performed in accordance with institutional restrictions with respect to Coronavirus (which means new subjects cannot be actively enrolled and most research staff will be limited with respect to access to other data sources for the time being).

Any changes to this study must be submitted with an Amendment Request Form before they can be implemented.

This approval is effective for 12 months from the date of this letter. Upon completion of your study please submit a **Study Completion Form**.

If you require more time to complete your study, you must request an extension in writing before this approval expires. Please submit an **Annual Review Form** with your request.

PLEASE QUOTE THE ABOVE REFERENCED PROJECT NUMBER ON ALL FUTURE CORRESPONDENCE

Good luck with your research,

Kristina Trim, PhD, RSW
Chair, HiREB Student Research Committee
McMaster University

The Hamilton Integrated Research Ethics Board (HiREB) represents the institutions of Hamilton Health Sciences, St. Joseph's Healthcare Hamilton, Research St.

Joseph's-Hamilton and the Faculty of Health Sciences at McMaster University and operates in compliance with and is constituted in accordance with the requirements of: The Tri-Council Policy Statement on Ethical Conduct of Research Involving Humans; The International Conference on Harmonization of Good Clinical Practices; Part C Division 5 of the Food and Drug Regulations of Health Canada, and the provisions of the Ontario Personal Health Information Protection Act 2004 and its applicable Regulations; for studies conducted at St. Joseph's Healthcare Hamilton, HIREB complies with the Health Ethics Guide of the Catholic Alliance of Canada

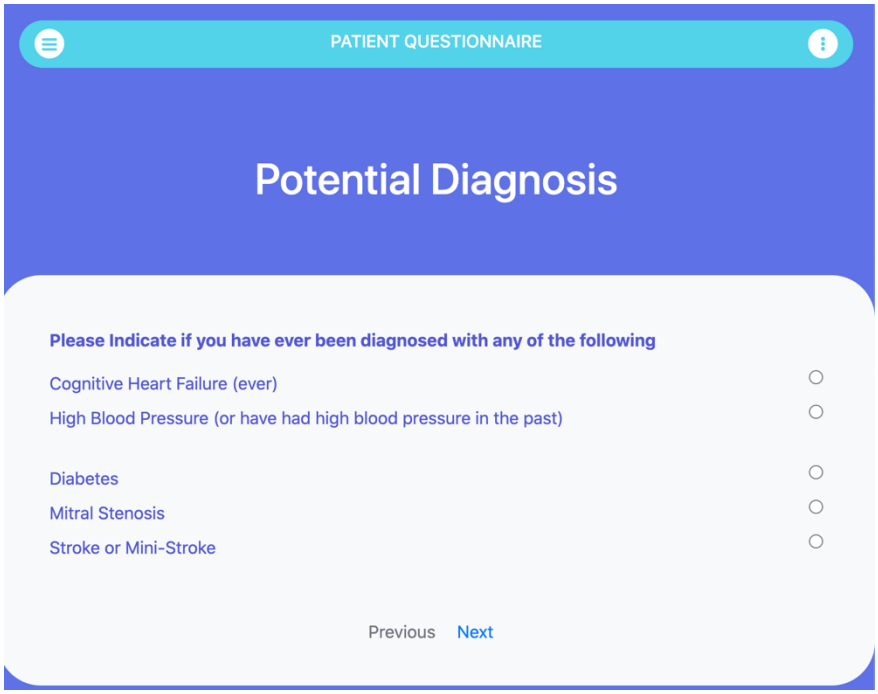
Appendix I: Results of Heuristic Evaluation

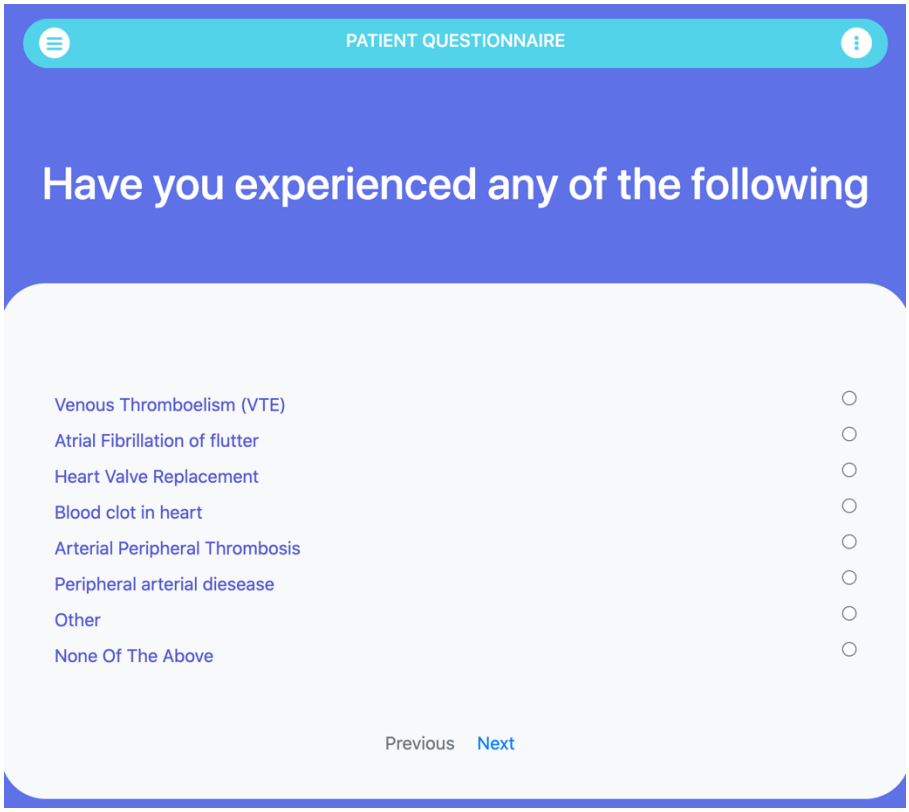
Severity	Issue
	Visibility of System Status
3	For Patient screens - dots at bottom should light up so patient knows how far they are, or consider a "% complete" bar, or even just "Screen 1 of x"
0	Headings at the top of page bolded to show patients which page they are on
	Match between System and Real World
1	Welcome screen - remove "Register option. Login screen Add "Don't have an account?" above the "Register" button.
4	Preliminary questions - language has to be understandable by patients. Remove "Bridging" because we don't want patient to be able to change this
3	For "Have you had a blood clot while your blood thinner was interrupted" Should give an option of "I don't know" Also, remove title of "Reason for Treatment with blood" from that screen.
3	Remove "Reason for Treatment with Blood" (it is confusing). Add layman terms for each one. Also, ask the question, "Have you experienced any of the following - can pick more than one". Also "none of the above". For each option, should ask whether within 3 months or not (or not sure). Remove "Cardiomyopathy".
3	"VTE screen" Layman's terms, must be able to pick more than one, should be an option for "not sure" for both DVT/PE question and for timing
3	"Heart Valve replacement", needs to take into account could be more than one valve. "Position" should be at top, for each one they select, should expand to give option for 'Tissue or Mechanical", and also "Bileaflet, ball and cage, tilting disc" and give "I'm not sure" for each question.
3	"Potential Diagnosis" - Date for most recent event should only show up if they select "stroke", and add layman terms, should be an option for "Done" on scroll wheel, not just "Clear or cancel"
3	"Current Drugs" Edoxaban (Lixiana) should be on this screen rather than with "Antiplatelets"; Add "75 mg" option for dabigatran; give an option for "none of the above" and "not sure"; for Xarelto - one option should be 15mg once daily (right now 15mg twice daily is shown twice), also 20mg should be once daily; If once daily, give option for "morning" "later in the day (not morning)"
2	"Current drugs 2" change to number for each day (instead of calendar) and must accommodate decimals at least to three places. Change to "Same daily" [spelling]; must be option for "not sure"
3	"Antiplatelets" remove edoxaban and move it to "Current Drugs". Change question to "Are you currently taking any of the following?" and, add option of "none of the above". Also, dose and frequency should expand below any selection of drug they make.
2	"Lab location" should only come up for those who selected "warfarin" or "acenocoumarol" in "current drugs 2", ideally this screen should come up right after "current drugs 2" for those patients

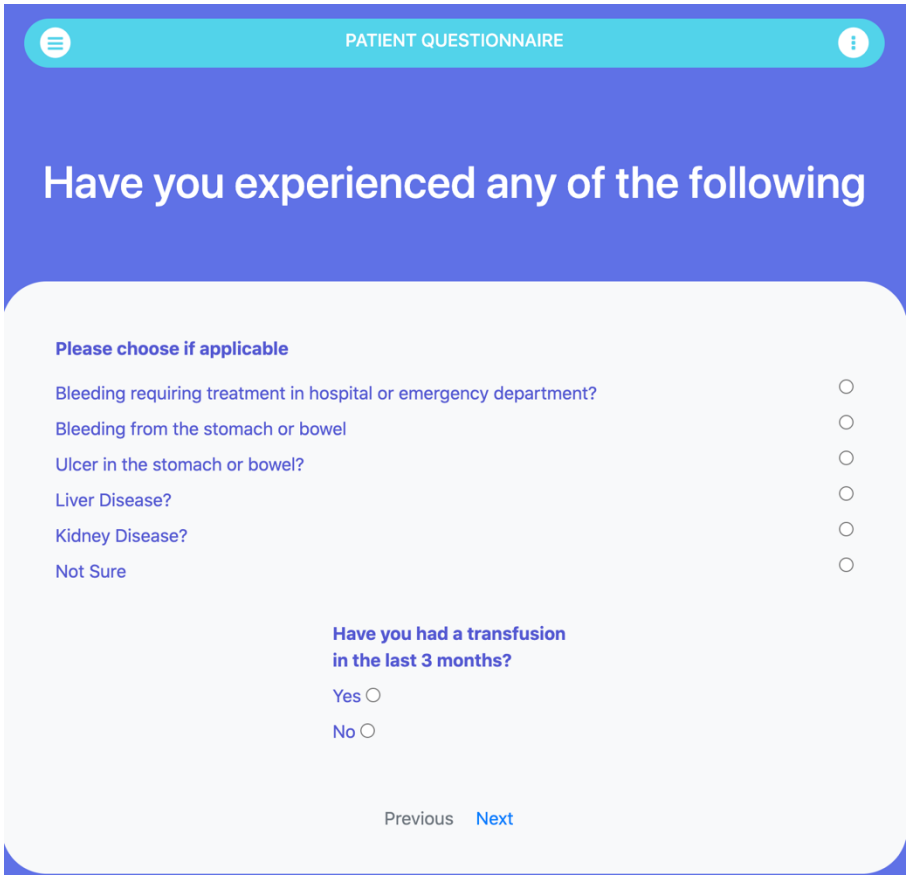
3	"Bleeding risk factors" - change question to "Have you experienced any of the following: "Bleeding requiring treatment in hospital or emergency department". "Was it in the last 3 months - Y/N/not sure" (also for "bleeding from stomach and bowel") Need to be able to pick more than one option. Remove "date of last emergency visit"; add "Not sure" to "have you had a transfusion in the last 3 months". Ulcer in the stomach or bowel - "Diagnosed in the last 3 months"
2	"Other medical conditions" Y/N/not sure
3	"Cancer" - need to be able to choose both chemo and radiation. Can just give option for "ongoing" check box. Don't need finished.
2	Page 2 -> Open text for weight but give one unit of measurement (lbs)
1	Page #6 Potential for patient to have both mechanical and tissue heart values, allow option to pick both. Add another button for both
2	Page #7 - Be able to select multiple options
4	Page #9 - showing calendar days instead of MG/day input for medications
User Control and Freedom	
2	Preliminary questions - can "Age" and "Weight" be a scroll wheel. Ideally should be able to choose units for weight.
3	All screens should have a clearly labeled "Next" and "Back" button.
2	Get rid of top bar in patient screens. What is it for? We do not want patients to be able to leave the screen, enter as nurse, etc.
3	"Current Drugs" need an option for "No"
1	"Thank you" at end of patient section, should have "Go back" and "OK"; If they press "OK" it takes them to "patient or nurse" screen.
4	Need to ensure that all "Back" buttons work.
Error Prevention	
3	Should be an easily visible option to "Clear all entries on this screen" for every data entry screen
2	"Reason for treatment with blood" free text should only come up if they choose "Other"
3	"Current Drugs" - Double page for current drugs, one needs to be removed
3	"current drugs 2" need to have "neither"
2	If we can have a not sure option for every MC question, then we should not allow people to move to next screen unless all questions are answered
2	Ask patient in "Surgery screen" for date of procedure, give calendar option, and also "not sure"
Recognition rather than recall	
2	"Antiplatelets" Aspirin - dose should be free text, and frequency should be once daily, twice daily, or other (or not sure); plavix - dose should be 75 mg or other (or not sure), frequency should be once daily or other (not sure); ticagrelor dose should be 60 mg or 90 mg, frequency should be twice daily or other (not sure); prasugrel dose should be 5mg or 10mg or other (not sure), and frequency once daily or other (not sure).

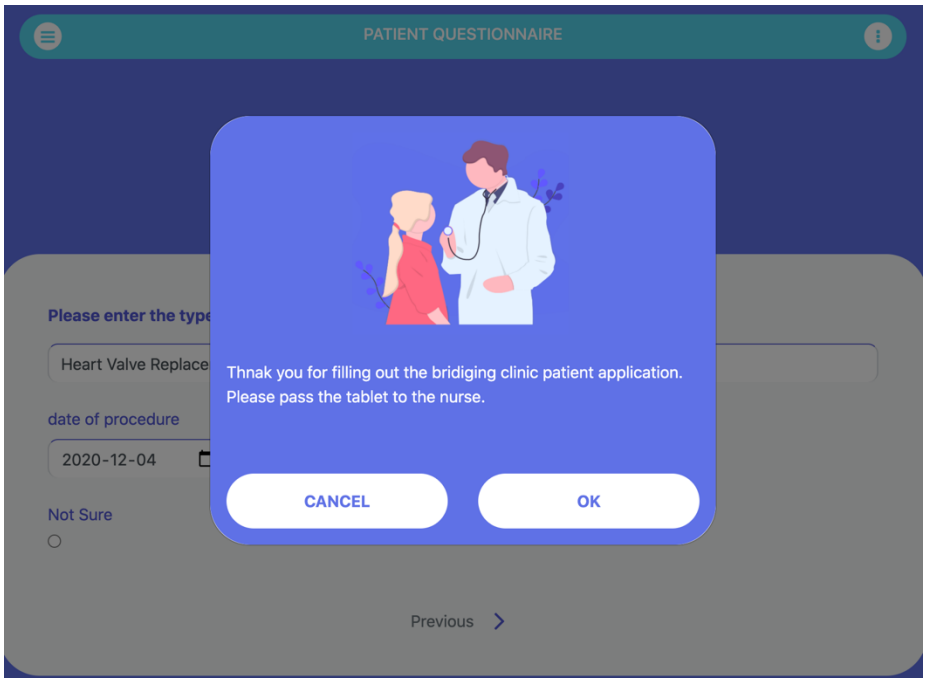
Flexibility and efficiency of use	
3	On "Reason for Treatment with blood", pt should be able to pick more than one option. Therefore, if they pick VTE or heart valve, it should give a drop-down, or expand/collapse rather than taking to a new page.
Aesthetic and minimalist design	
1	Preliminary Questions - "physician" spelled wrong
1	Potential Diagnosis - High blood pressure, change language to more formal terms.
1	"Current drugs" - "if once daily…" and "other free text" should only come up if selected
1	"Current Drugs", would be better if dosage expanded directly below the drug they chose rather than at the bottom; any free text box should only come up if "other" selected. And get rid of "Other" option, and replace with "none of the above"
1	"Current Drugs 2", same daily (Dialy is the wrong spelling)
1	"Cancer" - change to "are you being treated for cancer?" Also, if they choose "Yes" then options should expand above the "no"
4	"Surgery" Change to "Procedure" and just have free text, remove drop-down altogether. The drop-down will be moved to nurse's section.
1	Final page (Thank you spelled incorrectly)
4	Nurse "Bridging Summary" Page 3 - LMWH options should only come up if LMWH is triggered by algorithm
4	"Final Report" should be a text dictation. That is what will be put in the medical record.
Consistency and Standards	
1	Remove Register Button from welcome screen, keep on sign in screen add "Do not have an account?"
1	Page #4 "Disease is spelt incorrectly"
1	Page #4 Capitalize all letters
1	Page #15 - change to "Are you being treated for cancer"
3	Preliminary questions - Age and weight should state units.
1	Reason for Treatment for Blood - add the word Thinner to the title.

Appendix J: Thrombo-Link's Simple UI (Screenshots)






PATIENT QUESTIONNAIRE
Have you experienced any of the following
Please choose if applicable
Bleeding requiring treatment in hospital or emergency department?
Bleeding from the stomach or bowel
Ulcer in the stomach or bowel?
Liver Disease?
Kidney Disease?
Not Sure
Have you had a transfusion in the last 3 months?
Yes
No
Previous
Next


PATIENT QUESTIONNAIRE
Please enter the type
Heart Valve Replace
date of procedure
2020-12-04
Not Sure
Thnak you for filling out the bridiging clinic patient application.
Please pass the tablet to the nurse.
CANCEL
OK
Previous