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Towards a Cardiology/EHR Interaction Workflow Usability Evaluation Method

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Abstract

Understanding physician cognitive workflow while using Electronic Health Records (EHRs) and how the user interface interaction can support cognitive workflow is essential to premium patient care. One way to further understand the relationship between physician cognitive workflow and the user interface is through usability evaluations. The purpose of this paper is to present, test and analyze a usability evaluation method that is robust and yet flexible enough to understand the complexity and needs of a physicians' cognitive workflow when using an EHR system. Further, our usability evaluation method was designed from the perspective of the physician, rather than an information technology perspective. Important contributions of this study are that we demonstrate a way to evaluate an EHR in the actual cardiac care setting and produce results that identify actionable and realistic system improvement recommendations.

1. Introduction

Acute chest pain accounts for approximately 5.4% of all emergency department visits in the United States [1]. In the US, nearly 6 million patients will develop heart disease and approximately 600,000 will die annually [2, 3]. While over 50% of acute chest pain cases represent non-cardiac conditions, symptoms are often uncharacteristic, making it difficult to diagnose [4]. Failure to quickly and accurately determine the cause of chest pain has serious implications for cardiologists and their patients. The application of health information technology is a promising approach to more effective triage decisions; yet current electronic health record (EHR) systems often do not meet the demands for integrating complex clinical workflows [5-7]. In fact, it is possible that introducing additional information available through EHR systems may cause additional cognitive load for physicians [8, 9].

Thus, understanding physician cognitive workflow while using EHRs and how the user interface design can support cognitive workflow is essential. One way to further understand the relationship between physician cognitive workflow and the user interface is through user interface usability evaluations. In fact, usability issues experienced by clinical providers are gaining visibility; however, EHR testing frameworks are nascent, and there are few empirical studies to document how to best approach this complex situation. Without a well-tested research method for understanding how physicians interact with the EHR system to accomplish their tasks in caring for patients, it is questionable if EHR systems will reach their potential of improving patient care.

The purpose of this paper is to present, test and analyze a usability evaluation method that is robust and yet flexible enough to understand the complexity and needs of a physicians' cognitive workflow when using an EHR system. For complex user interfaces, the user interface usability evaluation process needs to be able to be operational in a reasonable amount of time, require a practical amount of resources, and not be overly complex, yet powerful enough to handle a specialized medical team working on a complicated cardiology case. To this end, this paper presents a descriptive case study on how a cross-disciplinary research team designed a multi-faceted usability evaluation (MUE) instrument and protocol to explore the interactions between cardiologists and the EHR system user interface. In this study, the multi-faceted usability evaluation (MUE) instrument has been used at a large Midwest medical center to observe and measure how well the EHR user interface accommodates the cardiologist's workflow while caring for patients with acute chest pain.

The remainder of the paper is structured as follows: The next section presents background information on EHR workflow issues for myocardial infarctions cases, human computer interaction, usability evaluation, and cognitive walkthroughs. Section 3 discusses various clinical provider EHR interactions models. Section 4 presents our research method, design, and pilot. The paper is concludes with a discussion of lessons learned, limitations, and directions for future research.

2. Background information

2.1. EHR workflow issues in myocardial infarctions cases

When patients arrive at an emergency department and are having chest pains, cardiologists have less than 30 minutes to assess the situation and determine a course of action for those with myocardial infarctions. Cardiologists have to interact with a number of information systems such as electrocardiograms (EKG), pharmacy, personal health records (PHR), laboratory results, and cardiac imaging studies as well as the EHR system. Having patient information available in a format that matches the cognitive workflow of the cardiologists is a challenge, but absolutely necessary. Access to evidence-based and technology-enabled data at the point of care promises improved outcomes for patients [10]. The American College of Cardiology, a nonprofit medical society, has taken an active role in addressing the complexity of care by promoting the use of the EHR in data registries, decision support, quality improvement, and reporting [11]. Using an integrated electronic health record system has long been viewed as a way to reduce the cognitive workload; however, in many cases it may in fact increase cognitive workload and fatigue [12]. The inability to reach these goals stimulated investigation by the American Medical Informatics Association's Task Force on Usability, which recommended human factors research to improve EHR usability [13]. Attention to usability for EHR system designs that support the cognitive work of clinical providers is also recognized as a requirement by the Healthcare Information and Management Systems Society [14]. Usability is defined by the International Standards Organization (ISO) as the "effectiveness, efficiency, and satisfaction with which specific users can achieve a specific set of tasks in a particular environment" [15]. While the benefits of a usability-based approach to EHR requirements are well documented, the practical application of usability assessment into EHR software design and development is limited.

We propose to address this gap by focusing our study on the specific medical practice of cardiology. In this paper we present a comprehensive cognitive walkthrough approach that accommodates an interdisciplinary team of health care providers and incorporates complex cardiology scenarios that include approved patient care protocols. As an outcome of this study, we aim to validate the MUE as a robust EHR usability evaluation method to gather data and analyze user input.

2.2 Human-computer interaction

The domain of human-computer interaction (HCI) provides tools for understanding the interaction between humans and computers. Interaction with various types of users takes place through the system's user interface [16]. HCI is concerned with the design, evaluation, and implementation of interactive computing systems and the study of major phenomena surrounding the use of the system [17]. HCI contributes techniques, methods, and guidelines for designing better and more "usable" artifacts that support interaction between human and system [18].

Usability is a quality that makes systems easy to learn and easy to use which often results in reducing the cognitive workload needed to use the system. Usability includes the consistency of the interface with other systems that the user experiences, as well as consistency within the different parts of the same system. Also included is the ease with which the user can manipulate and navigate the system, the clarity of interaction, ease of reading, and the arrangement of information as well as the speed of processing information. Another component essential to usability is the visual layout of information – the density, structure, and color [19]. Information technology research has long asserted that the study of usability factors such as organization, presentation, and interactivity is key to the successful design and implementation of user interfaces [20, 21]. Research suggests that usability is associated with positive effects, including reduction in the number of errors, enhanced accuracy, a more positive attitude on the part of the user toward the target system, and increased usage of the system by the user [22].

2.3 Usability evaluation

Usability testing, an evaluation approach from the HCI domain, provides a bottom-up approach to study how users interact with a system to accomplish their goals. Usability testing is a set of methods to determine whether an information system meets usability criteria for specific types of users carrying out specific tasks [19]. The ISO definition of usability (ISO-9241-11) contains three components - *efficiency* is a measure of the resources expended by the user to complete tasks accurately and completely, *effectiveness* is the accuracy and completeness of specified goals in a particular context, and *satisfaction* represents the comfort and acceptability of the work system to its users and other people affected by its use [15]. There are multiple approaches to usability testing, which may include evaluation of a real system or a representational, or mock-up system, and real users or representational users, which may involve developers or usability experts [23]. EHR usability has also been evaluated with criteria of usable, useful and satisfying [24] using the TURF (Task, User, Representation and Function) framework. TURF describes an EHR as usable if it is easy to learn, useful if it allows users to accomplish their work goals, and satisfying if the user likes the system and also considers it usable and useful. TURF is a comprehensive and detailed framework that adds the study of usefulness to further explore a systems view of functionality. Other usability evaluation methods include cognitive walkthroughs, heuristic evaluation, and software guidelines along with open-ended interviews and surveys [21].

For the purposes of this study, we will use the ISO definition of usability, and focus on detailed user interactions for a limited set of tasks within the domain of cardiology. Our instrument includes measuring efficiency, effectiveness, and satisfaction. Further, we have selected the cognitive walkthrough (with modifications) approach as the usability evaluation method to study *real* users interacting with a *real* EHR system.

2.4 Cognitive walkthrough

The cognitive walkthrough (CW) is a usability evaluation method that explores the impact of design decisions on the user's problem-solving processes and the user's ability to learn to use a system through exploration [25]. Early use of CW was summative, and occurred near the end of the design cycle, using software developers as subjects. It is now often employed as a formative tool to evaluate prototype designs with the system's intended end users, providing early feedback of unintended consequences not foreseen by the system designer. Planning of a CW includes defining the systems users, which tasks will be studied, the correct sequence of actions for each task, and how the interface will be constructed [26].

In addition, using the Think Aloud method, subjects are asked to verbally explain what they are thinking as they complete the scenario tasks using the software, allowing evaluators to understand the actions and processes experienced by the user [27]. The interaction is observed to evaluate the ease with which the user will select the correct action and complete it. An additional observer assists the moderator by recording task times, successful task completion, and other relevant information. After the walkthrough, each task is examined in sequence [19, 21, 28], and task times are recorded. This information is available as input to the requirements definition for system interface design.

Advantages to the use of CW over other approaches to usability testing include a better understanding of the user's goals and assumptions, the identification of unintended problems arising from interaction with the system, including increased cognitive processing and reduced workflow. The CW is a direct method which can utilize real users, real systems, and real task scenarios. Disadvantages include the relative high cost of evaluation when compared to other types of usability studies, due to the amount of time to prepare, conduct, and analyze the data. Potential bias may be introduced by task selections that do not represent the user's work leading to incomplete understanding of user's problem solving process [29]. In addition, an emphasis on low level details may underestimate the complexity of workflow for highly complex systems [30].

2.5. Clinical provider EHR interaction models

Electronic health record systems have been studied for over 30 years. Despite the benefits of information technology in other complex knowledge domains such as nuclear power and aerospace, progress in health information technology has been slow. Adoption has been hampered by EHR interfaces that are not integrated smoothly into clinician workflow [31-33]. While some evidence indicates that EHR systems are improving access to information, contradictory findings highlight the difficulty in assessing the progress that has been made since the introduction of EHR systems [34, 35]. This gap is further documented by studies verifying the dissatisfaction of clinical providers with the additional time needed for medication and procedure ordering and patient physical and history documentation, although they believed the EHR is necessary for improved patient care [12]. This negative impact on workflow was observed even among savvy super-users, and led us to propose a framework to study the interaction between the cardiologist and the EHR system (Figure 1) [36].

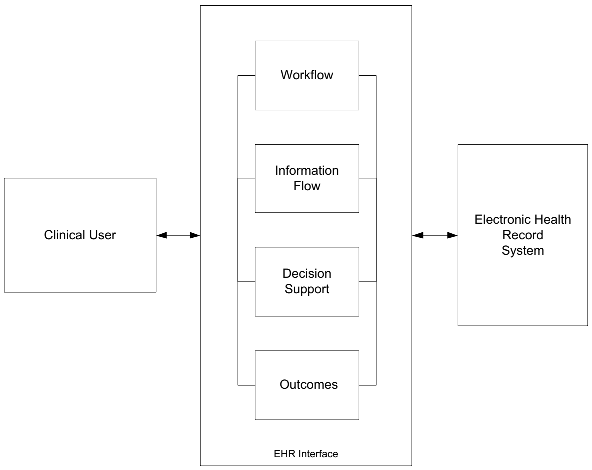

Figure 1. Clinical user EHR interaction model (adapted from [36])

Interaction between the EHR and the clinical user is grouped into four themes: workflow, information flow, decision support, and outcomes. *Workflow*, as defined by the study's participants, is the complex physical interaction of the clinical user with the EHR system and with information sources and destinations, to capture, retrieve, and process data. This is often expressed as the amount of time to complete an interaction. *Information flow* is the communication of information between clinical user and patient, as well as communication within the healthcare team. *Decision support* describes the use of technology to deliver guideline-based recommendations for patient care at the point of care. *Outcomes* is a theme that describes the use of data in a structured and summarized way to satisfy research, outcomes and billing, and includes the capture of data in the appropriate formats. The experience of interaction between clinical user and the EHR system takes place through the system's user interface. These themes are individually important for clinician acceptance of the EHR as being effective, efficient, and satisfying, and are also interdependent; therefore changes in functional capabilities in one area may have consequences in other areas. For example, the need for entry of detailed patient data to support registry data (outcomes) comes at a price of reduced workflow, because of the time required to complete documentation. Previous findings indicate that EHR system interface design is not informed by examining the clinical user's interactions, resulting in low acceptance and satisfaction with the overall EHR system, despite increasing rates of adoption [36]. The MUE framework introduced and validated in this paper was specifically designed to measure the workflow interaction shown above. We selected work flow because there is a strong void in this area and also workflow for physicians is much different than other disciplines and it is especially important in patient care in emergency situations. A natural option to study workflow is in human computer interaction domain and to measure workflow interaction effectiveness by applying usability evaluation techniques such as the CW. We discuss these topics next.

3. Research Method

The multi-faceted usability evaluation (MUE) instrument is used to study the workflow interaction between the EHR and the cardiologist using a task-based scenario for inpatient cardiac care. In this study, we discuss the design and demonstrate the use of the MUE as an instrument for EHR usability evaluation in the department of cardiology at a large Midwest medical center.

The EHR system evaluated in this study was introduced 30 years ago for mid-size to large ambulatory medical groups, hospitals, and integrated healthcare organizations. The integrated system supports administrative functions including billing, registration and scheduling; as well as clinical functions such as patient documentation, medication ordering and clinical decision support for various medical providers. It is one of the top three EHR systems in the US, and is widely used within large hospital systems.

An application specifying the selection of participants for the study, and the use of realistic patient data was submitted to the local Institutional Review Board (IRB). It was approved as an exempt study.

3.1. Multi-faceted usability evaluation (MUE) instrument

In order to understand how well the EHR system accommodates the workflow it is important to examine all of dimensions (e.g. audio, video, data entry, and navigation), along with the contextual components of the task scenario and patient data. The MUE framework combines a portable usability lab, complex patient case scenario, and realistic patient data (Figure 1) to provide a comprehensive view of the user workflow. One of the main goals of the MUE is to be able to capture the participants' thoughts and cognitive workflow while they are using the EHR in a clinical environment. The MUE was designed by a research team consisting of physicians, information technology researchers, and healthcare informaticists. Our aim was to create a framework that addresses the complex, multi-disciplinary environment of cardiac inpatient care.

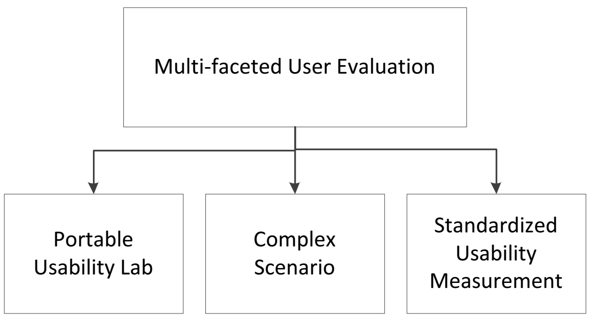

Figure 2. Multi-faceted user evaluation (MUE) instrument

3.2. Hardware Considerations

There were several important hardware requirements to take into consideration so that audio, video, data input/output, and system navigation data could be captured for further analysis. The clinical environment that we chose did not allow software to be installed on institutional computers to limit exposure of patient data to unauthorized users within the institution's network. To this end, a portable usability lab was needed.

The portable usability lab was designed to be self-contained, and connect easily to a user's clinical workstation. The lab (Figure 2) consisted of an Epiphan Systems VI2USB™ high definition digital video capture device which was connected by a USB to the user's monitor, capturing what the user is seeing and the actions s/he took. An external omnidirectional microphone was set up next to the user's computer to record "think aloud" comments" and any additional verbalization as the user completed the scenario. The software included "Audacity", an open-source audio editor, and recorder to capture live audio and convert it to an mp3 file. Both video and audio sources were connected to a laptop PC, which provided status of active recording, as well as data storage for large audio and video data files. Use of the portable lab did not require any changes to the user's PC, and satisfied the institution's restriction on software installation. Figure 3 models the configuration of the portable usability lab.

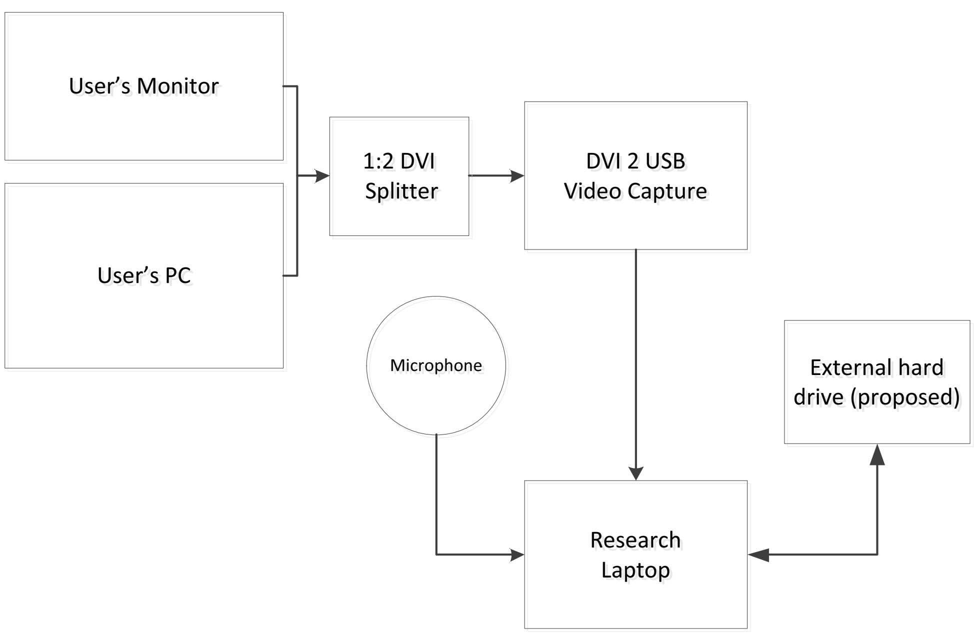

Figure 3. Portable usability lab schema

3.3. Environmental considerations

An important consideration for EHR usability studies is the context in which the evaluation takes place. The MUE is flexible and could take place in a clinical settings also, to accurately portray the complex environment of interruptions and multi-tasking typical of EHR usage.

3.3.1. Context

The importance of a well-chosen and developed scenario is essential to the discovery of a user's cognitive process. A disadvantage of CW is the choice of tasks that do not accurately represent the user's workflow. For our study, we chose the standardized cardiac inpatient scenario published in the National Institute of Standards and Technology (NIST) document 7804, which provides guidelines for the technical evaluation, testing, and validation of EHR usability [37]. The scenario was designed by NIST as a realistic clinical situation for assessing of EHR usability. The scenario was approved by the cross-disciplinary research team to appropriately address the tasks performed by the cardiologist in the care of acute cardiac patients. Tasks include documentation of patient status, ordering of laboratory tests and diagnostic procedures, modification of active medications, and creation of discharge information.

Figure 4 is an example of the complexity of one screen that a cardiologists views.

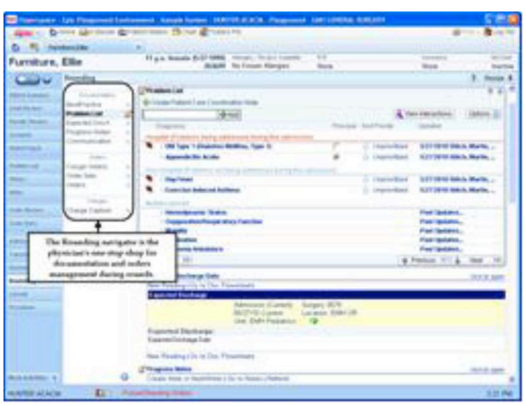

Figure 4. Sample EHR user interface

3.4. The usability evaluation protocol design

As described above, the MUE is a multi-faceted research instrument designed around the cognitive walkthrough usability evaluation method. MUE included input from a multi-disciplinary team of researchers consisting of physicians, HCI experts, and health informaticists. The team began by identifying the steps in the MUE process. The steps are listed below and flow chart showing the parallel steps of the participant and the investigators is shown in Figure 5.

1. The moderator described the purpose of the cognitive walkthrough.
2. A complex cardiac scenario was given to the participant to read.
3. The participant was instructed to complete the tasks defined in the scenario using the EHR system until all tasks were completed.
4. The assistant investigator digitally recorded the sessions, logging user's system interactions and completion times as they completed tasks. Observations, participants' comments while using the system, where and when system problems occur, and nonverbal user feedback were entered as field notes.
5. The participant was asked to complete the System Usability Survey.
6. The moderator then interviewed the participant with open-ended questions to get additional input on the user's experience.
7. After user was dismissed, a debriefing was conducted to collect additional data (possible improvements in structure of study, system set-up, etc.).

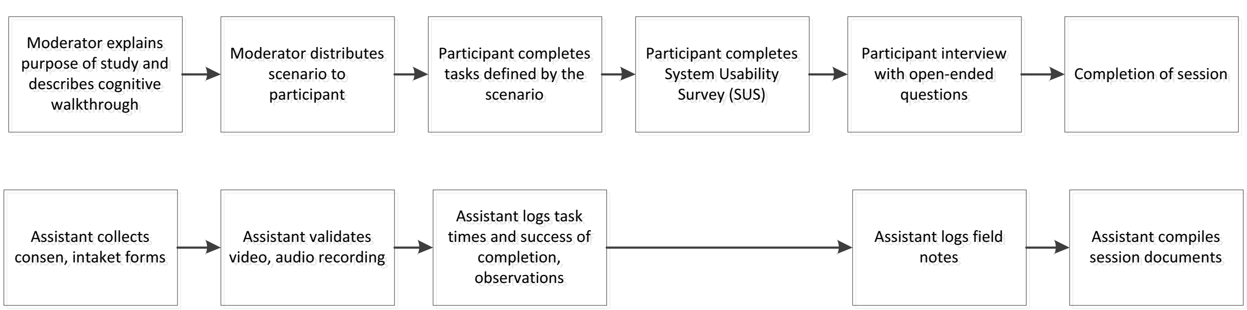

Figure 5. MUE flowchart of progress

Next the research team developed an observation scorecard to record data (see 0) and the System Usability Survey. Together, these artifacts captured data on the EHR effectiveness, efficiency, and satisfaction. We explain in detail how these parameters were applied.

1. Effectiveness includes task success and time to completion, and task failures – where the user abandoned the task or didn't reach the correct answer within the allotted time.
2. Efficiency is measured by variance of task time from anticipated time specified in the scenario, and any deviation from the path specified in the scenario. A post-walkthrough interview follows, where participants answer open-ended questions and discuss perceptions of usability and satisfaction [38].
3. Satisfaction is measured using an adapted System Usability Survey, a simple, short evaluation often used as a "quick and dirty" usability scale that has been modified to assess EHR usability [39]. The survey provides additional data about the user's ability to navigate the menu, the ease of finding information, as well as how satisfied they are with the system. Results from each session were captured on an observation scorecard (0).

3.5. Pilot

Next, the research team conducted a full-blown pilot to to test how well the portable usability lab worked using the MUE instrument. The session took place within the department of cardiology. The pilot took approximately 45 minutes. The participant, a cardiology fellow, was a frequent EHR user. The participant was comfortable with the "think aloud" request, and was reminded to speak loudly. The additional hardware of the portable usability lab was not perceived as intrusive. The EHR training system was used, and a test patient was chosen with similar characteristics to the profile of the patient described in the cardiac inpatient scenario. The participant completed the scenario, the system usability survey, and the interview. The materials were collected and the audio and video recording sessions were closed and saved on the laptop computer.

4. Discussion

4.1. Lessons learned

There were several lessons were learned from our pilot. First, the portable usability lab allowed us to take the study to the participant's work environment. This is important because it is difficult to simulate all the activities, interruptions, and instrumentation that impact the physician while using an EHR. We also evaluated how well the hardware and software met our needs. The microphone selected for use in the study was sensitive enough to pick up sound from the participant's computer – not only clicks, but fan noises, which made it difficult to hear the user's voice. We will need to further investigate how to adjust the sensitivity. Although, the screen capture capability was successful, allowing nearly 40 minutes of user screen displays. Audio was accurately captured in wav files. We were especially pleased with these results as we were able to use open source code and keep the pilot costs reasonable.

Second, we carefully considered how well the NIST cardiac inpatient scenario matched the cardiologists' expectations. We were interested if the scenario provided a representative number of tasks, as well as a structure for the recording of observations and task times and completion rates. We did find that some tasks in the scenario were not relevant to the cardiologist, and did not match the user's normal workflow. This is an important finding as we will not have multiple opportunities to re-do our study with cardiologists in the field because of other demands on their time. Future plans will include development of additional and complex scenarios that match the institutional setting.

We were pleased with the observation scorecard we developed specifically for this pilot. It was especially effective because all the data was captured in one place and in an organized manner. Further it reminded the observer of all the parameters that need to be logged during the 40 minutes session.

Third, setting up a test patient data to match the profile of the NIST scenario proved to be problematic in this setting, as access to the system was limited to trained users. So the non-medical investigators were not able to make modifications. For the pilot, an existing test patient exhibiting chest pain was selected, introducing mismatches with the scenario. For instance, a task requiring modification of active medications was not relevant, since Lasix was not ordered for the test patient. In the future we will need to spend even more time creating or searching for a test patient with relevant data (demographics, vital signs, labs, medications, etc.) to match the scenario, along with a process to "reset" the patient, restoring the original data, so that we have a repeatable process. We recognized that this could be a potential problem, but we needed to move forward with the pilot to provide additional information on how we might address these problems. Further, we had all the hardware and software in place including the physician willingness to participate.

In addition, several procedural items were noted. A secondary researcher in the role of observer is essential to capture task times and completions real-time, as well as to assist with set-up and take-down and ensure that video and audio capture is successful. It may also be necessary to have an IT professional to monitor the hardware and software. The assortment of connections, cords, and adapters, along with the additional devices required technical knowledge. Future plans will include some consolidation schema to minimize set-up and take-down once the environment moves to a clinical setting.

5. Conclusion

The purpose of this study was to introduce and test a cardiology/EHR Interaction workflow usability evaluation process to improve the design of EHRs to better match the workflow of physicians and ultimately reduce cognitive workload. There is a high penalty when an error occurs when using an EHR and thus this is why this research is so important. In our study we demonstrated and tested the techniques that work in a clinical environment. We have designed a robust method for cognitive workload usability evaluation and have found a way to actually implement and test it in a complex cardiology environment.

The limitations of this study as one might expect is that we need to further test the MUE instrument with more subjects. The research team intends to extend MUE instrument to apply to an interdisciplinary team of participants such as nursing, emergency, and family practice. This can provide potential benefits that include standardized user interfaces required by all EHR systems based on similarities across user groups and the specification of new EHR functionality to support the variation observed among user groups.

Further, future studies will introduce new scenarios designed with domain expert team members to further study elements of workflow, information flow, decision support, and outcomes.

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Appendix A. Cognitive walkthrough score sheet - Adapted from NISTIR 7804 - Technical Evaluation, Testing, and Validation of the Usability of Electronic Health Records, 2010.

Task Assignment	Easily Completed	Completed with difficulty	Not completed	Task Time	Correct Path	Minor Deviations	Major Deviations	Target Task Time	Participant Task Rating 1=Very Easy to 5=Very Difficult
1 - Document nitroglycerin under the tongue given in the ER by a nurse per verbal order 3 hours after admission									
2 - Enter vital signs [Blood pressure (BP) 172/95, heart rate 90]									
3 - Order labs									
4 - Modify active medications									
5 - Review labs									
6 - Document DNR status									
7 - Determine status of STAT medication that was ordered a few hours before									
8 - Return to finish the documentation for the handoff									
9 - Day 2. Review morning labs and vital signs									
10 - Transfer all inpatient medications to outpatient medications									
11 - Print discharge summary									
12 - Print a report for a hospital administrator that shows how the organization is doing on the quality measure about how soon nitroglycerine is given to patients with chest pain in the emergency department.									