Determining the Impact of Usability Issues of Primary Care Physicians by Expertise When Using an Electronic Health Record

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By

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The undersigned, appointed by the dean of the Graduate School,

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DETERMINING THE IMPACT OF USABILITY ISSUES OF PRIMARY CARE PHYSICIANS BY EXPERTISE WHEN USING AN ELECTRONIC HEALTH RECORD

Presented by Martina A. Clarke

A candidate for the degree of

Doctor of Philosophy

And hereby certify that, in their opinion, it is worthy of acceptance.

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ABSTRACT

Background: EHRs with poor usability present steep learning curves for new resident physicians, who are already overwhelmed in learning a new specialty. This may lead to error prone use of EHR in medical practice by new resident physicians. The goal of this study is to identify usability-related and performance-related differences in use patterns that arise between primary care physicians by expertise when using an EHR.

Methods: We compared usability measures after three rounds of usability tests (Round 1: November 12, 2013 to December 19, 2013; round 2: February 12, 2014 to April 22, 2014; Round 3: February 02, 2015 to March 05, 2015). There is presently no evidence-based approach to measure a user's EHR experience; therefore, novice and expert physicians were distinguished based on clinical training level and number of years using the EHR. In round 1, ten novice physicians and six expert physicians participated in the study. In round 2, eight novice physicians and four expert physicians participated in the study. In round 3, nine first year residents participated as novice resident physicians and 18 expert resident physicians (8 second year and 10 third year) participated in the study. Lab-based usability tests using video analyses were conducted to analyze learnability gaps between novice and expert physicians. Physicians completed nineteen tasks, based on an artificial but typical patient visit note. We used a mixed methods approach including quantitative performance measures (percent task success, time on task, mouse activities), a survey instrument of system usability scale (SUS), qualitative narrative feedback during the debriefing session, subtask analysis, and debriefing session with physicians.

Results: Although the sample size was too small to do reliable tests of significance, the finding show that there were mixed changes in performance measures and expert physicians were more proficient than novice physicians on some performance measures. Geometric mean values of percent task success rates were compared between the two physician groups across three rounds. There was a 6 percent point increase in novice physician group's percent task success rate between round 1 and round 2 (R1: 92%, CI [90%, 100%]; R2: 98%, CI [90%, 100%]). There was a 3 percent point decrease in novice physician group's percent task success rate between round 2 and round 3 (R2: 98%, CI [90%, 100%]; R3: 95%, CI [90%, 100%]). There was a 3 percent point increase in novice physician group's percent task success rate between round 1 and round 3 (R1: 92%, CI [90%, 100%]; R3: 95% CI [90%, 100%]). Expert resident physicians had a 7 percent point increase in percent task success rate between round 1 (90%, CI [90%, 100%]; 97%; CI [90%, 100%]). There was a 1 percent point decrease in expert resident physician group's percent task success rate between round 2 and round 3 (R2: 97%, CI [90%, 100%]; R3: 96%, CI [90%, 100%]). There was a 6 percent point increase in expert resident physician group's percent task success rate between round 1 and round 3 (R1: 90%, CI [90%, 100%]; R2: 96%, CI [90%, 100%]). Geometric mean values of time-on-task (TOT) were compared between the two physician groups across three rounds

Geometric mean values of time-on-task (TOT) were compared between the two physician groups across three rounds. There was a 9% decrease in novice resident physicians' time on task between round 1 and round 2 (R1: 44s CI [32s, 62s], R2: 40s CI [27s, 59s]). There was a 5% decrease in novice resident physicians' time on task between round 2 and round 3 (R2: 40s CI [27s, 59s], R3: 38s CI [28, 52]). There was a 14% decrease in novice resident physicians' time on task between round 1 and round 3 (R1: 44s CI [32s, 62s], R3: 38s CI [28s, 52s]). There was a 21% decrease in expert resident physician group's time on task between round 1 and round 2 (R1: 39s CI [29s, 51s], R2: 31s CI [22s, 42s]). There was a 26% increase in expert resident physicians' time on task between round 2 and round 3 (R2: 31s CI [22s, 42s], R3: 39s CI [28s, 54s]). There was no improvement in expert resident physicians' time on task between round 1 and round 3 (R1: 39s CI [32s, 62s], R3: 39s CI [28s, 54s]). Geometric mean values of mouse clicks were compared between the two physician groups across three rounds. There was a 25% decrease in novice resident physicians' mouse clicks between round 1 and round 2 (R1: 8 clicks CI [6 clicks, 13 clicks], R2: 6 clicks CI [4 clicks, 11 clicks]). There was a 33% increase in novice resident physicians' mouse clicks between round 2 and round 3 (R2: 6 clicks CI [4 clicks, 11 clicks], R3: 8 clicks CI [5 clicks, 13 clicks]). There was no improvement in novice resident physicians' mouse clicks between round 1 and round 3 (R1: 8 clicks CI [6 clicks, 13 clicks], R2: 8 clicks CI [4 clicks, 11 clicks]). Similarly, there was a 25% decrease in expert resident physicians' mouse clicks between round 1 and round

2 (R1: 8 clicks CI [5 clicks, 11 clicks], R2: 6 clicks, 95% CI [1 clicks, 11 clicks]). There was a 33% increase in expert resident physicians' mouse clicks between round 2 and round 3 (R2: 6 clicks CI [1 clicks, 11 clicks], R3: 8 clicks, CI [5 clicks, 12 clicks]). There was no improvement in expert resident physicians' mouse clicks between round 1 and round 3 (R1: 8 clicks CI [5 clicks, 11 clicks], R3: 8 clicks CI [5 clicks, 12 clicks]). Geometric mean values of mouse movement, length of the navigation path to complete a given task, were compared between two physician groups across three rounds. There was a 14% decrease in novice resident physicians' mouse movements between round 1 and round 2 (R1: 9,247 pixels CI [6,404 pixels, 13,353 pixels], R2: 7,992 pixels CI [5,350 pixels, 11,936 pixels]). There was a 6% increase in novice resident physicians' mouse movements between round 2 and round 3 (R2: 7,992 pixels CI [5,350 pixels, 11,936 pixels], R3: 8,480 pixels CI [6,273, 11,462]). There was an 8% decrease in novice resident physicians' mouse movements between round 1 and round 3 (R1: 9,247 pixels CI [6,404 pixels, 13,353 pixels], R3: 8,480 pixels CI [6,273, 11,462]). There was also a 14% decrease in expert resident physicians' mouse movements between round 1 and round 2 (R1: 7,325 CI [5,237 pixels, 10,247 pixels], R2: 6,329 pixels, CI [4,299 pixels, 9,317 pixels]). There was a 30% increase in expert resident physicians' mouse movements between round 2 and round 3 (R2: 6,329 CI [4,299 pixels, 9,317 pixels], R3: 8,235 pixels CI [5,953 pixels, 11,392 pixels]). There was a 12% increase in expert resident physicians'

mouse movements between round 1 and round 3 (R1: 7,325 CI [5,237 pixels, 10,247 pixels], R3: 8,235 pixels CI [5,953 pixels, 11,392 pixels]).

Geometric mean values of time-on-task of nineteen tasks between resident physicians by clinical year: year 1, year 2, and year 3. A lower number of seconds usually indicate higher performance and higher number of seconds usually indicate lower performance for time on task. There was a 5% decrease in physicians' time on task between year 1 and year 2 (Y1: 38s CI [28s, 52s], Y2: 36s CI [25s, 52s]). However, there was a 6% increase in physicians' time on task between year 2 and year 3 (Y2: 36s CI [25s, 52s], Y3: 38s CI [28s, 53s]). From year 1 to year 3 there was only no increase in physicians' time on task. Geometric mean values of mouse clicks were compared between the three physician groups (year 1, 2, and 3). A lower number of mouse clicks usually indicate higher performance and higher mouse clicks usually indicate lower performance for mouse clicks. There was a 13% decrease in physicians' mouse clicks between year 1 and year 2 (Y1: 8 clicks CI [5 clicks, 13 clicks], Y2: 7 clicks CI [4 clicks, 12 clicks]). There was a 14% increase in physicians' mouse clicks between year 2 and year 3 (Y2: 7 clicks CI [4 clicks, 12 clicks], Y3: 8 clicks CI [6clicks, 12 clicks]). From year 1 to year 3 there was no improvement in physicians' mouse clicks. Geometric mean values of mouse movement, length of the navigation path to complete a given task, were compared between three physician groups: year 1, 2, and 3. There was a 7% decrease in physicians' mouse movements from year 1 to year 2 (Y1: 8,480 pixels CI [6,273 pixels, 11,462 pixels], Y2: 7,856 pixels CI [5,380 pixels, 11,471 pixels]). There was a 6% increase in physicians' mouse movements from year 2 to year 3 (Y2: 7,856 pixels CI [5,380 pixels, 11,471 pixels], Y3: 8,319pixels CI [6,101 pixels, 11,343 pixels]). From year 1 to year 3 there was a 2% decrease in physicians' mouse movements (Y1: 8,480 pixels CI [6,273 pixels, 11,462 pixels], Y3: 8,319pixels CI [6,101 pixels, 11,343 pixels]).

Thirty-one common and four unique usability issues were identified between the two physician groups across three rounds. Five themes emerged during analysis: six usability issues were related to inconsistencies, nine issues concerning user interface issues, six issues in relation to structured data issues, seven ambiguous terminology issues, and six issues in regards to workarounds. Themes were created by analyzing and combining usability issues to form an overarching theme (1). Five themes emerged during analysis: six usability issues were related to inconsistencies, nine issues concerning user interface issues, six issues in relation to structured data issues, seven ambiguous terminology issues, and six issues in regards to workarounds. An example of an inconsistency issue was Illogical ordering of lists in task 17: Add a medication to your favorites list, where medication list could not be sorted alphabetically when imported into a patients visit note. This may frustrate physicians when they cannot discern how to sort the medication list. An example of a user interface issue was the long note template list physicians had to deal with when they complete task 1: Start a new note. There was a lengthy list of different templates to choose from when

creating a note. The templates were not specialty specific that to search through template list and choose a desired template was time demanding and caused extra cognitive load. An example of a structured data issue was a lack of distinction between columns in task 9: Include Family History. In the task of documenting family history, the blue or white columns (indicating negative vs. positive finding) for the family member were unlabeled so physicians were unsure how to mark a family history item ‘positive.’ An example of an ambiguous terminology issue was multiple fields having the same functionality. When completing tasks 14 & 15, there was no clear difference between the drop-down menus labeled ‘Requested Start Date’, the drop-down menu labeled ‘Requested Time Frame’, and the radio button labeled ‘Future Order.’ This could cause future labs to not get ordered properly so labs may not be completed at the right time and patients may have to get the test redone, which brings additional cost to the patient. An example of a workarounds was unawareness of functions. When completing task 13: Include diagnosis, physicians were not able to move ‘hypertension’ from the problem list to the current diagnosis list so they re-added ‘hypertension’ as a new problem. This takes more time for physicians to search for the diagnosis and add it to the active problems list.

Conclusions: This study found differences in novice and expert physicians’ performance and usability issues, demonstrating that physicians’ proficiency did increase with EHR experience on some measures. Training physicians to use the EHR may decrease difficulty of completing tasks in the EHR. Improving physician

training may reduce the amount of workarounds created that may lead to workflow problems. These results highlight the areas of difficulty resident physicians with different experience levels are currently facing, which may potentially improve the EHR training program and increase physicians' performance when using an EHR. Future directions include exploring associations between performance measures and usability issues should also be studied.

CHAPTER 1: INTRODUCTION

Physicians' use of the EHR:

Meaningful Use (MU) is one measure of successful adoption of electronic health records (EHRs) as a component of the Health Information Technology for Economic and Clinical Health (HITECH) act proposed by the Office of the National Coordinator for Health Information Technology (ONC) and Centers for Medicare & Medicaid Services (CMS). EHRs are "records of patient health information generated by visits in any health care delivery setting" (2). Health information technology's (HIT) functionality in clinical practice is expanding and physicians are increasingly adopting EHRs as a result of the financial incentives guaranteed by CMS (3). National Center for Health Statistics (NCHS) reported, in a data brief in 2013, 78% of office-based physicians have adopted EHRs in their practice (4). Some advantages expressed by EHR users of adopting an EHR consist of: increased adherence to guidelines in preventive care, decrease paperwork for providers, and an improvement to overall quality and efficiency in patient care (5-7). Nonetheless, there are possible drawbacks to EHRs, which comprise of: financial burdens, mismatch of human and machine workflow models, and productivity loss potentially caused by EHR usability issues (5, 6, 8-10). Usability is described as how sufficiently a software can be used to perform a particular task with effectiveness, efficacy, and content (11). EHRs with poor usability may have a negative effect on clinicians' EHR learning experience. This could lead to increased cognitive load, medical errors, and a decline in quality of patient care (12-17). Learnability is defined as the extent to which the system permits users to understand how to use its application (18). Learnability deals with the amount of time and effort needed for a user to develop proficiency with a system over time and after multiple use (19). In the literature, while there are variations in defining usability and learnability (20-22), definitions of learnability are strongly correlated with usability and proficiency (21, 23, 24). Allowing physicians to efficiently accomplish clinical tasks within the EHR, may ease some time constraints experienced by physicians during patient visits.

According to the EHR user satisfaction survey in 2012 completed by 3,088 family physicians, approximately 62% of survey respondents were not satisfied with many of the best-known EHR systems, and EHR vendor support and training were the areas with lowest satisfaction ratings (25). Multiple studies on successful EHR implementations have stressed the usefulness of training in the implementation process (26-37). A survey by Aaronson et al. (34), of 219 family practice residency programs concerning EHR use in the residency program indicated that resident physicians' EHR training may have an impact not only on the perceived ease of use of the EHR system, but also may impact the use of EHR systems in their practices after residency.

Presently, EHRs require a large investment of effort for users to attain a certain level of proficiency. Resident physicians were selected for this study because residents who are not adequately trained on using an EHR may experience a steep learning curve when beginning their residency program (38). In an effort to maximize physician proficiency with the EHR, hospitals and clinics provide comprehensive EHR trainings for their resident physicians. However, it is challenging to find sufficient time to train physicians to use new EHR systems (30, 33, 39, 40).

Physicians' use of CPOE:

Adverse drug events (ADEs) caused over $3.5 billion in additional medical costs (41). As an approach to decrease medication errors and patient harm, the Institute of Medicine (IOM) advises using a Computerized Provider Order Entry (CPOE) system (42). CPOEs are computer aided medication ordering from an electronic device that is often integrated into EHRs. With the ongoing implementation of MU stage 2 as a part of the EHR incentive program, any licensed healthcare professional is required to use CPOE for medication, laboratory, and radiology orders to be eligible for MU incentive payments. A major advantage of CPOE is medication error reductions that are caused by illegible handwriting or incorrect transcription (43). CPOE systems may include functionalities, such as, alerts about adverse drug reactions, which may promote reduction in errors. However, there is also some evidence that the use of CPOE may cause increase in clinician work, undesirable workflow issues, and generation of new kinds of errors (44, 45). Poor usability of CPOE, has been shown to reduce efficiency, decrease quality of patient care, and frustrate clinicians (46). For a CPOE to be used effectively and efficiently, the system should allow physicians to complete medication orders accurately without causing adverse drug events.

Importance of primary care:

Primary care provides medical care for a significant amount of common illnesses and account for a great number of patient visits (47, 48). Between 2009 – 2010, approximately 46% of all ambulatory care visits were by primary care physicians (49) and approximately 75% of physician office visits involve drug therapy (50). With the healthcare reform underway, an increase in patients will induce a shortage of primary care providers which may reduce the time physicians' spend with patients thereby increasing the duties of primary care physicians (51). Primary care physicians, who frequently are not adequately trained on EHR use in their medical schools and have started learning their new specialty, have to cope with a steep learning curve on EHR use. This may negatively influence their learning experiences, especially in health care settings with poor EHR usability. This, in turn, may lead to high cognitive load, medical errors, and decreased quality of patient care. Allowing physicians to efficiently execute clinical tasks within the EHR, particularly CPOE functionalities may release some time constraints experienced by physicians while caring for patients.

Previous studies have shown the importance of usability testing and evaluation in the EHR adoption and implementation process and current best practices promote utilization of cognitive approaches to assess human–computer interactions within the EHR system (52-56). For instance, a systematic review by

Khajouei and Jasper, examining the impact of CPOE medication system's design aspect on usability, found that proper system design of CPOE is essential to increase physicians' adoption and to reduce medication errors(46). A cognitive approach was used when Li et al conducted usability testing using think-aloud protocol analysis with clinical simulations to evaluate clinical decision support and found 90% of negative comments associated with navigation and workflow issues (57). Heuristic evaluation has been also been used to identify usability issues in multiple articles. Chan et al., conducted a heuristic evaluation of a CPOE order set system and uncovered 92 unique heuristic violations across 10 heuristic principles (58). A study by Harrington and Porch, analyzing an EHR's usability, identified 14 usability heuristics that were violated 346 times in the intensive care unit's clinical documentation(59).These studies were successful in identifying usability issues among users, however, there is a lack of studies comparing novice and expert physicians when using an electronic health record and this paper seeks to identify the differences between the two physician groups.

Better understanding of usability issues between novice and expert physicians in the EHR will assist novice physicians in learning to use the system more effectively and efficiently which may lead to improved quality in patient care. While much attention is paid to financial and technical evaluations, there have been no systematic EHR usability evaluation studies conducted. We are also not aware of any other systematic usability studies being conducted on EHR use at University of Missouri Health Care (UMHS). This project will provide the

University and the health care industry with research agenda on how EHR systems, with varying degrees of usability factors, influence the quality, safety, efficiency, and effectiveness of clinical performances delivered in patient care.

EHR training in primary care

With the increase in patients, physicians' may have less time to allot to patients during clinic visits (51). EHRs are said to reduce physician workload, however, physicians who are not appropriately trained on using an EHR in medical school may encounter a steep learning curve and experience issues when using the EHR in clinical practice (60). Multiple studies on how to successfully implement EHRs have continuously stressed the usefulness of training in the implementation process (26-37). A survey by Aaronson et al. (34), of 219 family practice residency programs concerning EHR use in the residency program indicated that resident training may have an impact not only on the perceived ease of use of the EHR system, but also may impact the use of EHR systems in their practices after residency. According to the EHR user satisfaction survey in 2012 completed by 3,088 family physicians," approximately 62% of survey respondents were not satisfied with many of the best-known EHR systems, with EHR vendor support and training the area with lowest satisfaction ratings (25). Inadequate EHR training combined with poor usability may have a negative effect on physicians' learning experience. Residents who are not adequately trained on EHR use in medical school experience a steep learning curve on EHR use (38). This could lead to increased cognitive load, medical errors, and a decline in quality of patient care (12-15).

Role of usability evaluation in improving EHR usability and training

Previous studies have shown how important usability evaluation is in the EHR adoption and implementation process (52-54). Current best practices promote the use of cognitive approaches to examine human–computer interactions in the EHR system (55). A study by Li et al. evaluated a clinical decision support (CDS) system using usability testing with think aloud protocol and then conducting a near live clinical simulation with a simulated patient. This study found that 90% of negative comments were concerning navigation and workflow issues. Participants mentioned a need for added flexibility to permit diverse ways of using the CDS based on users' varying practice styles and situational contexts. These results were used to improve the overall design of the CDS system (57). Chan et al., performed usability testing of a computerized physician order entry (CPOE) order set system using heuristic evaluation and discovered 92 unique heuristic violations across 10 heuristic principles (58). The most common heuristics violations were: Visibility of System Status, Consistency and Standards, Aesthetic and Minimalist Design, Error Prevention, and Helps Users Recognize, Diagnose and Recover from Errors. The results of Chan et al study were given to the vendor for consideration, who addressed the usability issues and incorporated the findings into future designs. A study by Harrington and Porch investigating an EHR's usability recognized 14 usability heuristics that were violated 346 times in the intensive care unit clinical documentation (59). The top 3 heuristics violation were Match (33.8%), Language (32.4%), and Minimalist (15.9%) and were responsible for 82% of the heuristic violations. The findings were a part of discussions with information systems department which was receptive to maximizing the usability of the EHR. Kushniruk et al. conducted a study at an urban medical center in NYC probing the association between usability tests and training of a commercial EHR system (60). The most common issue identified was attempting to locate a matching term in the system when entering medications and diagnoses. Users also found documentation of clinic visits to be tedious and had issues with the EHR occasionally crashing during use. For example, when the EHR prompted the user to complete a required entry, one user was not able to locate where to input the missing information. The study further found numerous areas of possible improvement for system learnability and usability, and recommendations were made for improving EHR training. The results of the studies mentioned above suggest that there usability evaluation can play an important role in improving EHR usability and training.

Objectives

Identify usability-related and performance-related differences in use patterns that arise between novice and expert resident physicians when using an EHR.

a. Compare physicians by clinical year (Year 1, Year 2, Year 3)

b. Compare novice and expert resident physicians by three rounds of data collection (round 1, round 2, round 3).

Quantitative and qualitative methods, including, lab-based usability tests, were used to determine the difference in performance between 30 primary care physicians with varying expertise when using an EHR. Morae Manager was used to calculate performance measures: task percent success, time on task, mouse clicks, and mouse movements and conduct sub task analysis.

Hypothesis: Expert resident physicians will perform better at tasks than novice resident physicians and experience fewer and different usability issues than novice resident physicians.

Definition of terms

Acute Illness: An illness that has an abrupt onset and a short-term course. Acute illness symptoms tend to be more severe, but are not necessarily life-threatening. Examples include colds, flu, appendicitis, most infectious diseases, and headaches (61).

Adverse Drug Event (ADE) – Side effect or complication from a medication (62).

Assessment - An examiner's evaluation of the disease or condition based on the patient's subjective report of the symptoms and course of the illness or condition and the examiner's objective findings, including data obtained through laboratory tests, physical examination, medical history, and information reported by family members and other health care team members (63).

Chief Complaint (CC) – A patient's description of the symptoms or other reasons for seeking medical care from a provider (62).

Chronic Diseases – Prolonged conditions that rarely improve and often cannot be cured (62).

Electronic Health Record (EHR) - "The Electronic Health Record (EHR) is a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting. Included in this information are patient demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data, and radiology reports (64)."

History of Present Illness (HPI) - An account obtained during the interview with the patient of the onset, duration, and character of the present illness, as well as of any acts or factors that aggravate or ameliorate the symptoms. The patient is asked what he or she considers to be the cause of the symptoms and whether a similar condition has occurred in the past (65).

Information Need - A gap or deficit in knowledge that might be rectified by information and/or education provision (66).

Past Medical History (PMH) - A list of a patient's past health problems, surgeries and specialists (67).

Physical Exam (PE) – The process by which a doctor investigates the body of a patient for signs of disease (68).

Plan - This is what the health care provider will do to treat the patient's concerns - such as ordering further labs, radiological work up, referrals given, procedures performed, medications given and education provided (69).

Progress Notes – Notes about a patient's medical condition that are made during or after a physician-patient encounter (62).

Review of Systems (ROS) – Inventory of body systems obtained through a series of questions seeking to identify signs and/or symptoms that the patient may be experiencing or has experienced (70).

Significant Lab Data (Labs) – Lab values from tests that is done in the laboratory where the appropriate equipment, supplies, and certified expertise are available (71).

CHAPTER 2: LITERATURE REVIEW

Method

Objective and goals of the study

The objective of this review is to determine the difference in performance between expert and novice users to eventually improve the EHR training program for new users of the EHR. The study addresses the following research question:

- How do expert and novice users differ in performance measures: task percent success, time on task, mouse clicks, and mouse movements?
- Is there a difference in usability issues that expert and novice users encounter when using an EHR?

Search Strategy

To identify relevant studies, a search of the English-language literature was conducted in PubMed™ (National Library of Medicine, Bethesda, MD), CINAHL™ (Ebsco, Ipswich, MA), and SCOPUS™ (Elsevier, Neuchâtel, Switzerland) databases. The Medical Subject Heading (MeSH) terms used were: Medical Records Systems, Computerized, Task Performance and Analysis, and User-Computer Interface. Other terms used were: usability evaluation, usability testing, usability, new, user, new user, beginner, novice, master, experienced, trained, skill, skilled, and expert.

Inclusion and exclusion criteria

Titles and abstracts were screened to determine articles that would receive a full document review. Selection criteria for inclusion were abstracts that contained information relating to usability testing of novice and expert users when using an electronic health record. The search was limited to studies between the years 2000 and 2015 to capture a range of publication years, methodologies.

Articles excluded from this review were studies that focused on usability testing of other health information technology and studies that did not compare novice and expert users. Additional exclusion criteria were studies written in another language, and studies that did not include usability evaluation of an electronic health record.

Study selection process

Error! Reference source not found. shows a flow chart of the review of literature to finalize selected articles to include in this review. The search for articles began with electronic databases. Inclusion and exclusion criteria in the first database, PubMed identified 29 citations. CINAHL was the second electronic database, which resulted in 1 citation and the third electronic database was SCOPUS, which revealed 120 citations. In addition to the use of these research databases, hand-searching of article references from relevant papers was also performed to identify any further studies that may have been overlooked by the database literature. After applying inclusion and exclusion criteria, studies that passed the abstract screening process were added to the articles that received full document review. After examination of 7 full articles, 4 final articles were identified to be a part of the review.

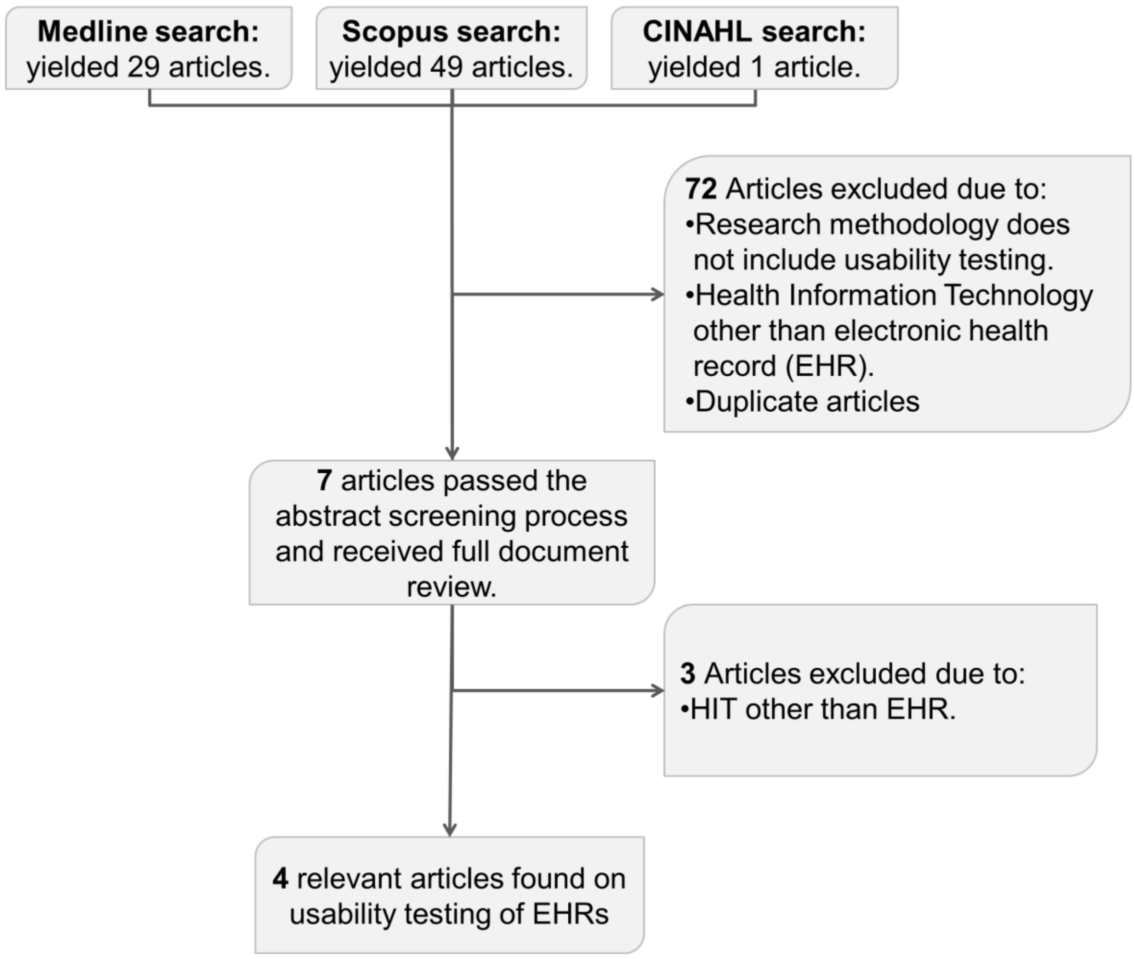

Figure 1. Flow diagram on the exclusion of literature to yield a finalize articles to include in this review.

Results

Characteristics of the studies on performance between expert and novice users included in this review

Table 1 summarizes 4 articles on performance between expert and novice users sorted by the publication year. The number of novice participants for the selected studies ranged from Corrao et al. (72) 4 participants to 19 participants in the study conducted by Lewis et al (73). The number of expert participants for the selected studies ranged from Lewis et al (73) 0 participants because of the use of prediction software to 42 participants in the study conducted by Corrao et al. (72). The studies reviewed were conducted in multiple countries, including the United States (72-74)and Denmark (75). The user groups included in these articles were: hospital nurses (75), emergency department (ED) nurses (74), oncology physicians (72), and health sciences students (73).

Kjeldskov, Skov, Stage's study included as their novice sample, seven clinically experienced nurses who were novice computer users and had completed the electronic patient record course for the EPR implementation the following week. The same seven experienced nurses were used as the expert sample 15 months later, who became higher general computer users and had used the EPR 10-20 times/ 2 hours per day. In Kim et al's study, newly hired nurses on the job for less than two months were included as the novice sample and nurses who were working in the ED using the same EHR for more than 2 years were considered experts. In Corrao et al.'s study, physicians who had no previous exposure to the EHR system were considered novice users and 12 hematology-oncology fellows and 30 attending who used the system for at least 1 year were considered expert users. In a study done by Lewis et al. novice participants were required to be adult, novice touchscreen EMR users, without prior experience using a touchscreen interface for an EMR. No participants were included as expert users. A prediction software was used to estimate performance times for a skilled user.

Various research methodologies were utilized to assess the difference in performance between expert and novice users. Effectiveness/task success (73-75), efficiency/time on task (73-75), task load index (75), mouse clicks (74), mouse movement (74), system usability scale (74), heuristic violations (72), Efficiency (72), Satisfaction (72), Learnability (73), and Rate of error (73). Participants were required to complete specific tasks during the usability evaluations. Kjeldskov et al's participants completed seven tasks, participants in Kim et al's study completed nine tasks, Lewis et al's participants completed thirty-one tasks, and the number of tasks were not mentioned in the study completed by Corrao et al.

Three out of the four studies mentioned identifying usability issues: Kjeldskov, Skov, Stage identified 103 usability issues, Kim et al., usability issues but did not mention a number, Corrao et al., identified 110 heuristic violations, and Lewis et al. did not report any usability issues identified.

Table 1: Summary of studies selected for evaluation on the differences in performance between expert and novice users when using an electronic health record

Study	Novice Methodology	Expert Methodology	Country	Novice Sample Population	Expert Sample Population	Aim	Measurements
Kjeldskov, Skov, Stage, 2008	A longitudinal study - a usability evaluation was conducted with novice users when an electronic patient record system was being deployed in a large hospital.	After the nurses had used the system in their daily work for 15 months, the evaluation was repeated.	Denmark	Seven experienced nurses who were novice computer users, completed EPR course and faced implementation the following week (n=7)	Same seven experienced nurses who became higher general computer users and had used the EPR system 15 months 10-20 times/ 2 hours per day (n=7)	Inquire into the nature of usability problems experienced by novice and expert users, and to see to what extend usability problems of a health care information system may or may not disappear over time, as the nurses get more familiar with it—if time heals poor design?	Effectiveness/Task success, Efficiency/Time on task, Task load index
Kim et al., 2012	Standard usability tests using video analysis, including four sets of performance measures, a task completion survey, the system usability scale (SUS), and sub-task analysis	Standard usability tests using video analysis, including four sets of performance measures, a task completion survey, the system usability scale (SUS), and sub-task analysis	United States	Newly hired nurses on the job for less than two months (n=10)	Nurses who were working in the ED using the same EHR for more than 2 years	Investigated the usability gaps in the Emergency Department Information System (EDIS) as ten nurses differentiated by two experience levels	Task success, Time on task, Mouse clicks, Mouse movement, Usability issues, System usability scale

Corraco et al., 2010	Four novice users evaluated an EHR product and identified issues. Scenario- based exercises of common tasks were created by the junior medical informaticist. The evaluation protocol included a think-aloud technique to have the novice users speak their thoughts as they worked through the exercises.	A panel of five experts reviewed the identified issues to determine agreement with and applicability to the already implemented system. A survey of 42 experienced users of the previously implemented EHR was also performed to assess efficiency and general satisfaction.	United States	Physicians who had no previous exposure to the EHR system (n=4)	12 hematology-oncology fellows and 30 attendings who used the system for at least 1 year (n=42)	Examine the role of usability testing in the evaluation of an EHR product and whether novice users could identify issues with usability that resonated with more experienced users of the system	Heuristic violations, Efficiency and Satisfaction
Lewis et al., 2010	Seven mock patient encounters with an actor playing the role of a patient. Participants completed 31 tasks using the EMR software	CogTool was used to predict estimated performance times for skilled use.	United States	Participants were required to be adult, novice touchscreen EMR users, without prior experience using a touchscreen interface for an EMR. (n=19)	Prediction software used to estimate performance times for skilled use.	Determine the relative efficiency of novices compared to a prediction of skilled use when performing tasks using the touchscreen interface of an EMR developed in Malawi	Task Success, Efficiency/Time on task, Learnability, Rate of error,

Difference in performance between expert and novice users

Effectiveness/task success

Effectiveness was measured in the form of task success. In Lewis et al's, novice users completed 96% of task performances successfully. When participants were required to use an onscreen keyboard for specific tasks, those tasks had the most performance errors (70%) and the lowest rate of task success (83%) (73).

Geometric mean was used to compare the two nurse groups' percent task success rates of nine tasks across two scenarios in Kim et al's study. No statistical difference was found between the two nurse groups' geometric mean values neither for scenario one (60%, expert group vs. 62%, novice group) nor scenario two (66%, expert group vs. 55%, novice group) (74).

In Kjeldskov et al's study, significant difference was based on a Wilcoxon signed rank test ($z = 2.116$, $p = 0.034$). Expert participants solved a mean of 6.29 (S.D. = 1.11) tasks and novice participants solved a mean of 3.57 (S.D. = 1.27) tasks. When completely solved tasks were analyzed, there was no statistical significance between novice and expert participants based on a chi-square test ($p = 0.0833$). Overall, the expert participants were more effective than the novices by solving significantly more tasks with less variation than the novices (75).

Efficiency/Learnability, time on task

Efficiency was measured in the form of time on task (TOT), which is the time taken to complete a specific task that was given. Shorter TOT was indicative of better performance. In Lewis et al's study, based on a Wilcoxon test, mean novice performance for every task was significantly slower than the predictions of skilled use calculated by CogTool (Wilcoxon Z ~.18.58, P < 0.001). However, novices performed tasks faster than the predicted skilled level in 208 (13%) of the observed task performances. In 444 (28%) of all observed task performances, novice participants performed within 20% of the predicted skilled level. (73).

Geometric mean was used to compare the two nurse groups' TOT success rates of nine tasks across two scenarios in Kim et al's study. Substantial difference was found in TOT between the two nurse groups for scenarios 1 (85s, expert group vs. 163s, novice group) and scenario 2 (84s, expert group vs. 133s, novice group). Novice nurses took 1.5‑2 times longer than expert nurses (74).

Kjeldskov et al found no significant differences in mean task completion times (z = 1.402, p = 0.161). Although not significantly faster, expert participants were faster for simple data entry tasks but on harder tasks, authors found no considerable differences between novice and expert participants (75).

Mouse activities

Kim et al's study was the only study that measured mouse activities. Mouse activities was measured in the form of mouse clicks and mouse movements. Lower values of both mouse clicks and movements were indicative of better performance. Geometric mean values of mouse clicks were compared and the expert nurse groups completed the tasks with a little fewer mouse clicks across all tasks for both scenarios. Geometric mean was used to compare the two nurse groups' mouse movement, length of the navigation path to complete a given task and the expert nurse group used slightly shorter mouse movements across the tasks for both scenarios (74). No p-values were given for mouse activities.

System usability scale and User Satisfaction Survey

Based on the survey completed by experienced participants in Corrao et al's study, experienced participants disagreed that the EHR improved efficiency. About 82.3% disagreed over the EHR reducing time searching for documents and forms, 70.6% disagreed over the EHR improving data access and accountability, 64.7% disagreed over the EHR enhancing data organization, and 64.7% disagreed over the EHR promoting more efficient documentation (72). When given the system usability scale survey in Kim et al's study (74), novice nurses rated the system usability at 55 (marginal) for scenario one and 43 (unacceptable) for scenario two. Experts rated it at 75 and 81 (excellent) for scenarios one and two (76).

Task completion survey, task load index

Based on task load index completed by participants in Kjeldskov et al's study, the novice participants experienced frustration significantly higher than expert participants (75). Based on participants' response to a task completion survey on how difficult it was to complete a given task in Kim et al's study, the expert nurses had all values below 3 (neutral) across the tasks for both scenarios, and novice nurses experienced difficulty with tasks 6, 9 in scenario 1 and task 8 in scenario 2, difficult. Values near 1 indicate ‘very easy ‘and 5 indicate ‘very difficult' (74).

Difference in usability issues between expert and novice users

Usability issues

Corrao et al identified 110 unique problems with the most heuristic violations in the categories of Match and Visibility. Match heuristic violations were mainly caused by a discord between the novice users' mental model and the way a specified task was completed using the system. Visibility heuristic violations emphasized a great deal of ways the system could have provide essential visual cues. After reviewing the findings of the usability test, the expert panel conceded that 99 (90%) of the 110 unique problems found by the novice users were legitimate (72). In Kim et al's study, three major usability issues were identified. Firstly, there was not a good use of space and data entry sections were scattered across the screen, which made it hard to determine useful information. Fields did not auto populate so nurses spent more time filling out redundant fields. Some of the data entry requirements were ambiguous which caused conflicting documentation Kim, 2012 #33316}. Kjeldskov et al found 103 usability problems and majority of the problems were related to three overall themes: (1) complexity of information, (2) poor relation to work activities, and (3) lack of support for mobility(75). Wilcoxon signed rank test was used to determine statistical significance. Eighty-three out of 103 of the usability problems were encountered by the novices and expert subjects encountered 63 of usability problems ($z = 2.159$, $p = 0.031$). Forty-three of the 103 usability problems were encountered by both the novices and the experts. Usability problems were rated as critical, serious and cosmetic and novices encountered

93% of the critical problems (25 of 27 problems) while the experts encountered 70% (19 of 27 problems) ($z = 1.420$, $p = 0.156$). Novices encountered 80% of the serious problems while experts encountered 61% ($z = 2.159$, $p = 0.031$). Novices experiences 65% of cosmetic problems while experts encountered 50% ($z = 1.876$, $p = 0.061$). Some problems vanished over time, but not all. After one year of use seventeen critical problems that novices encountered novices were still present. There was a large overlap of usability problems that were rated as critical and serious. New serious and cosmetic problems also appeared because experts began exploring other system functionalities. Overall, a high number of problems were encountered by novices and expert users but significantly more severe for the novices. So the problems that remained became less severe after 1 year of use (75).

Discussion and conclusion

Differences between expert and novice users

This study was able to identify differences in performance between expert and novice users when using an electronic health record. Novice EMR users in Lewis et al's study were able to perform at a skilled level some of the time within the first hour of system use. Kim et a's study found no statistical difference between the two nurse groups' geometric mean values for both scenarios (74). When completely solved tasks were analyzed in Kjeldskov et al's, there was no statistical significance between novice and expert participants based on a chi-square test (p

= 0.0833). These results are significant because one of the primary design goal of the EMR is to allow novice users to perform tasks efficiently and effectively so it is important for novice physicians to become experts in the shortest amount of time. Although there was no difference in effectiveness, there was a difference in efficiency of novice and expert participants. Experts showed higher efficiency than novice participants in studies done by Lewis et al (73) and Kim et al (73). Although not significantly faster, expert participants in Kjeldskov faster for simple data entry tasks. These results suggest that novice participants are able to complete tasks successfully but at a slower rate than physicians because of their unfamiliarity with the systems' functionalities.

Having novice users as a part of a usability study allows for more usability issues to be found (72, 75). Corrao et al's study was able to find a significant number of usability issues when reviewing the system using novice participants (72). In Kjeldskov et al's study, novice users also encountered majority of the usability issues identified in the study. However, Kjeldskov et al's argues that the use of expert participants assists in eliminating noise from "false" usability problems that they labelled as cosmetic in their study (75). Multiple studies were able to identify many usability issues, which demonstrates the importance of testing a software before making available to its audience.

Survey respondents in Corrao et al's study gave a higher than expected satisfaction rating even though they were not satisfied with the efficiency, flexibility, and accessibility of the system. In Kim et al's study, experts gave a higher SUS score than novice physicians. These results suggest that, after adapting to the implemented system and gaining a certain level of proficiency users more confident and willing to use the system (72, 74). Corrao et al used a survey to determine efficiency and general satisfaction with the EHR product (72). Surveys rely on the recollection of users, and users may not be able to remember all the issues that arose while using the product (72).

Limitations of this review

This review concentrates only on published studies. A possibility of publication bias can be included and was not investigated. This review also excludes non-English language studies. This review excluded usability studies that did not compare expert and novice users.

CHAPTER 3: METHODOLOGY

Study Design

To determine the impact of usability issues of primary care physicians by expertise when using an EHR, data was collected through usability testing using video analysis software, Morae® (TechSmith, Okemos, MI). Family medicine and Internal medicine resident physicians, performed nineteen artificial, scenarios-based tasks in a lab-based setting. A mixed methods approach was used to determine the performance-related and usability-related differences of primary care physicians. This involved four types of quantitative performance measures, system usability scale (SUS), a survey instrument (76), and qualitative debriefing session with participants. This study was approved by the University of Missouri Health Sciences Institutional Review Board.

Development of scenario

Two sets of artificial but realistic scenario based tasks were used in the study. The tasks were created based on discussion with an experienced physician champion (JLB) and two chief resident physicians from both participating departments (FCM, IM). When completing round 1 of the usability test, resident physicians were given the scenario:

> “You are about to enter the clinic exam room to see a patient who was recently hospitalized for pneumonia and discharged home on new prescription for home oxygen at 2 L per minute by nasal cannula and on oral Levaquin for 7 day course. This is the third day after hospital discharge, and

the fifth day of Levaquin. The patient had sodium of 129 on hospital admission and 131 on discharge. She needs a follow-up BMP today. Her blood pressure was low during the hospital course, and one of the blood pressure medications was being held at the time of discharge."

When completing round two of usability test, resident physicians were given the following scenario:

"You are about to enter the clinic exam room to see a patient who was recently hospitalized for heart failure. He was discharged home on new prescription for home oxygen at 2 L per minute by nasal cannula and on oral lisinopril 10mg daily. This is the third day after hospital discharge. The patient had potassium of 2.9 on hospital admission and 3.4 on discharge. He needs a follow-up BMP today. His blood pressure was low during the hospital course, and one of the blood pressure medications was being held at the time of discharge. ."

When completing round 3, of usability test, resident physicians were given the following scenario:

"You are about to enter the clinic exam room to see a patient who was recently hospitalized for gastroenteritis with dehydration and hyponatremia. This is the third day after hospital discharge. The patient had sodium of 122 on hospital admission and 131 on discharge. He needs a follow-up BMP today. The furosemide was held during the hospital stay and resumed on discharge at half the prior dose (40 mg twice a day instead of 80 mg twice a day)"

While different, these three scenarios were equivalent in difficulty, workflow, and functionalities used. These scenarios were used to assess physicians' use of the EHR that involves realistic inpatient and outpatient information. The progress note was intentionally straightforward as the goal was to study physician workflow when creating electronic documentation, not to assess medical knowledge or technical skills. Seven sections were included in the progress notes:

1. *Chief Complaint (CC)* which is a patient's description of the symptoms or other reasons for seeking medical care from a provider (62).
2. History of Present Illness *(HPI)* which is an account obtained during the interview with the patient of the onset, duration, and character of the present illness (65).
3. *Past Medical History (PMH)* which is a list of a patient's past health problems, surgeries and specialists (67).
4. *Review of Systems (ROS)* is an inventory of body systems obtained through a series of questions seeking to identify signs and/or symptoms that the patient may be experiencing or has experienced (70).
5. *Physical Exam (PE)* which is the process by which a doctor investigates the body of a patient for signs of disease (68).
6. *Significant Lab Data* (Labs) are lab values from tests that is done in the laboratory where the appropriate equipment, supplies, and certified expertise are available (71).

7. *Assessment* which is the examiner's evaluation of the disease or condition (63).
8. *Plan* which is what the health care provider will do to treat the patient's concerns (69).

Development of task list

Nineteen tasks that are generally completed by both novice and expert primary care physicians were included that physicians in both groups could execute. These tasks also met 2014 EHR certification criteria 45 CFR 170.314 for meaningful use (MU) stage 2 (19). The alphanumeric code located beside each task corresponds to the EHR certification criteria that satisfies meaningful use stage 2 objectives. In order to measure the learnability more effectively, we confirmed that the tasks were also practiced in the EHR training in which resident physicians were required to participate at the commencement of their residency. The tasks had a clear objective that physicians were able to follow without needless clinical cognitive load or ambiguity, which was not the study's aims. The tasks were:

- Task 1: Start a new note *(§170.314(e)(2))*
- Task 2: Include visit information *(§170.314(e)(2))*
- Task 3: Include Chief Complaint *(§170.314(e)(2))*
- Task 4: Include History of Present Illness *(§170.314(e)(2))*
- Task 5: Review current medications contained in the note (*§170.314(a)(6))*
- Task 6: Review problem list contained in the note *(§170.314(a)(5))*

- Task 7: Document new medication allergy *(§170.314(a)(7))*
- Task 8: Include Review of Systems *(§170.314(e)(2))*
- Task 9: Include Family History (*§170.314(a)(13))*
- Task 10: Include Physical exam *(§170.314(a)(4) and §170.314(e)(2))*
- Task 11: Include last comprehensive metabolic panel (CMP) (§170.314(b)(5))
- Task 12: Save the note
- Task 13: Include diagnosis *(§170.314(a)(5))*
- Task 14: Place order for chest X-ray *(§170.314(a)(1) and §170.314(e)(2))*
- Task 15: Place order for basic metabolic panel (BMP) *(§170.314(a)(1) and §170.314(e)(2))*
- Task 16: Change a Medication *(§170.314(a)(1) and §170.314(a)(6))*
- Task 17: Add a medication to your favorites list (§170.314(a)(1))
- Task 18: Renew one of the existing medications (§170.314(a)(1) and §170.314(a)(6))
- Task 19: Sign the Note

In round three, task 14 changed from Task 14: Place order for chest X-ray to Task 14: Place follow up visit in 1 month

Experiment Environment

In this study, PowerChart was displayed on a standard 15 inch laptop with 1024 by 768 pixels resolution using Windows 8 with the Internet Explorer browser. All experiments were run in conference rooms at University of Missouri Health

System (UMHS). Quantitative and qualitative usability measures were collected using usability software Morae® (TechSmith, Okemos, Michigan) (77) as the physicians perform clearly defined sets of clinical tasks using artificial representative primary care patient cases.

Each usability session was attended by a facilitator and a physician to streamline the evaluation process. The facilitator sat next to the physician and help them walk through given tasks throughout the session. The facilitator observed and documented user behavior, user comments, and system actions during the session and discussed these issues with the physician during the debriefing session for clarification purposes.

The goal of this study and the detailed clinical scenario with directions were prepared for the physicians to review at the start of each evaluation session. Physicians were read their rights as a participant that acknowledged: participation is voluntary, volunteers had the right to stop participating at any time, and although the session was recorded, volunteer privacy and personal identification was safeguarded. The facilitator also asked the physician if they had any questions.

The physician read the task description from the computer screen and began the task. Evaluators were encouraged to share their opinions verbally as they progressed through the session. Individual evaluation sessions were followed by debriefing sessions.

Organizational Setting

This study was conducted at the University of Missouri Health System (UMHS), a 536 bed, tertiary care academic medical hospital located in Columbia, Missouri. The Healthcare Information and Management Systems Society (HIMSS), a non-profit organization that rates how hospitals are implementing electronic medical record (EMR) application, has awarded UMHS with Stage 7 of the EMR Adoption Model (78). This means UMHS uses electronic patient charts, analyzes clinical data using data warehousing, and electronically shares health information with authorized health care entities (79). There are more than 70 primary care physicians at UMHS clinics throughout central Missouri and in 2012, had approximately 553,300 clinic visits. The Department of Family and Community Medicine (FCM) oversees six clinics and have over 100,000 patient visits at these clinics, while the Department of Internal Medicine (IM) oversees two clinics (80). UMHS' EHR contains a database which includes all the data from the university's hospitals and clinics. Within the EHR, the CPOE allows providers to electronically and securely access and place lab and medication orders for patients, and transmit the orders directly to the department that is responsible for completing the request. Conducting a usability study using the fully implemented EHR system within one of the most wired health care systems makes the aim of this study achievable.

Participants

There has been much debate about how many participants are needed in a usability test to reliably identify usability issues (81). In this study, we recruited 26 physicians from our family medicine department and 20 physicians from our internal medicine department. UMHS FCM and IM physicians were selected for the sample because, as primary care residents, they have comparable clinical roles and responsibilities. Currently there is no evidence-based way to measure a user's EHR experience so physicians were categorized by clinical experience and years using an EHR. CMS requires resident physicians providing patient care services with less than 6 months experience to have a teaching physician present (82). The assumption was that after one year of EHR use, resident physicians could gain sufficient skills to be considered an expert [52]. Thus, to identify differences in use patterns that arise between novice and expert resident physicians when using an EHR, in round 1, ten first year residents participated as novice resident physicians and six expert resident physicians (3 second year and 3 third year) participated in the study. In round 2, eight first year residents participated as novice resident physicians and four expert resident physicians (2 second year and 2 third year) participated in the study. In round 3, nine first year residents participated as novice resident physicians and 18 expert resident physicians (8 second year and 10 third year) participated in the study. Both FCM and IM run three-year residency programs. This was a cross sectional comparison. Physicians are being grouped by year of residency to determine if physicians become more proficient with EHR experience and to identify workflow differences between physician groups. Based on past evidence based research ten participants for each unique class of users is usually enough to uncover the most important usability issues (83). Convenience sampling method was used when selecting physicians (84). FCM physicians were recruited during weekly residents meetings and IM residents were recruited through MU's secure email client group emails. The information obtained was recorded so that physicians cannot be identified, directly or through identifiers linked to the subjects. All physicians were compensated for their time.

Informed Consent

The study was reviewed by the University of Missouri Health Sciences Institutional Review Board as an exempt project. A waiver of documentation of consent was included which clearly stated that participation in the study was completely voluntary and that the participant could stop the interview at any time if they no longer wish to participate in the interview without consequences.

Demographic and satisfaction survey

Demographic data was conducted so that sample can be divided into various groups based on demographic information gathered from the survey. Physicians completed a demographic survey to determine if each demographic characteristic have an effect on their EHR performance. In round one and two, demographic data collected included:

1. Gender
2. Age
3. Race
4. Computer skills
5. Experience with any other EHR than PowerChart

In round three additional questions included in the demographic survey were:

6. Year in residency
7. Confidence level when using EHR

8. Satisfaction with:
    a. Documenting in the EHR
    b. Creating orders in the EHR
    c. Seeking information in the EHR
    d. Reading notes in the EHR

Usability Software

We used Morae Recorder (TechSmith, Okemos, Michigan, USA) to capture participant screen actions and interactive behavior in real time. Morae® is a usability and market research software. For a software or web site usability test, Morae records desktop activity on the user's computer while a video camera records the user. Morae captures all system events, including mouse clicks, web page changes, onscreen text, and more.

Pilot Interview

Usability testing was validated by four pilot physicians conducted by the graduate research assistant (MAC) in a conference room at the University of Missouri. The purpose of piloting the usability test is to identify potential issues and identify tasks that may be misinterpreted by participants so that the task list and progress note could be revised before it was used during the usability test with other physicians.

Data Collection

Round 1 usability data was collected between November 12, 2013 and December 19, 2013, round 2 data was collected between February 12, 2014 and April 22, 2014, and round 3 data was collected began February 02, 2015 and concluded March 05, 2015. Round 1 data collection began three months after novice (year-one) resident physicians completed their initial mandatory EHR training at UMHS. Resident physicians were invited to complete round 2 approximately three months after the date they completed round 1. Usability testing was completed in approximately 20 minutes and was conducted on a 15-inch laptop using Windows 7 operating system. To preserve consistency and reduce undesirable interruptions, the participant and the facilitator were the only two individuals in the conference room. At the beginning of the session, the participant was advised that their participation in this study was voluntary and they had the right to end the session at any time. In round one and two, the participant was provided with a binder that contained the instruction on how to complete the task before the test began. In round 3, the instruction on how to complete the task and the tasks were displayed at the top of the display as the test progressed. Morae Recorder recorded audio, video, on-screen activity, and inputs from the keyboard and mouse. Participants completed the tasks without the assistance of the facilitator who would only intervene if there were any technical difficulties. However, there were no technical difficulties and facilitator did not have to intervene. After participants completed the tasks, they completed the SUS and demographic survey. The test session concluded with a debriefing session where participants were asked to comment on the specific tasks they found difficult. Interesting observations detected by the facilitator were discussed as well.

Data analysis

Performance metrics

We confirmed there were no EHR interface change between data collection of round 1 and round 2 that may influence the study and tasks otherwise. Performance metrics rely not only on user behavior but also on the use of scenarios and tasks. Performance metrics are the best way to evaluate the effectiveness and efficiency of a product. They are also useful in estimating the magnitude of a specific usability issue. Four fundamental performance metrics were used in this study:

1. Percent task success computes the percentage of subtasks that participants successfully complete error free.
2. Time-on-task measures the length of time each participant takes to complete each task. It begins when participant click on "start task" button to when the "end task" button is clicked.
3. Mouse clicks measures the number of times the participant clicks on the mouse when completing a given task.
4. Mouse movement computes in pixels the distance of the navigation path by the mouse to complete a given task.

For percent task success rate, a higher value usually signify higher performance, representing participants' skill with the system. For time on task, mouse clicks, and mouse movements, a higher value usually indicates lower performances (85-87). As such, higher values may represent that the participant had complications while using the system. Geometric mean were calculated for the performance measures with confidence interval at 95% (88). Performance measures have a strong tendency to be positively skewed so geometric mean was used because it provides the most accurate measure for sample sizes less than twenty-five (89).

System usability scale (SUS)

After testing, the participants were asked to complete the System Usability Scale (SUS) to supplement the performance measures. SUS is a ten-item Likert scale that provides fairly robust measures of subjective usability and is a widely used, validated instrument in HIT evaluation (19, 76, 90). SUS produces a single number that represent a composite measure of the overall usability of the system under examination. SUS yields a score from 0 to 100, with 100 being a perfect score (76). The SUS was used after the physician finishes the given scenario-based tasks, but before any debriefing or discussions take place. Physicians were asked to record their immediate response to each item, rather than thinking about items for a long time. Physicians were asked to score the 10 questions in the survey with one of five responses that range from Strongly Agree to Strongly disagree. SUS yields a single number representing a composite measure of the overall usability of the system being studied (76). SUS scores have a range of 0 to 100, with 100 representing a perfect score. A score of 0 to 50 is not acceptable, a score of 50 to 62 is low marginal, a score of 63 to 70 is high marginal, and a score of 70 to 100 was acceptable. The ten questions in the SUS survey are:

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

Usability Themes Analysis

The recorded sessions were examined using Morae Manager® using markers to code difficulties and errors the physicians had. Video analysis took approximately 1.5 hours for each 20 minute recorded session. The first step in analysis was to review the recorded sessions and label any tasks that were unmarked during data collection. The second step was to divide each of the nineteen tasks into smaller tasks (sub-tasks) to determine the subtle usability challenges. For example, each physician may complete the same task in various ways that physicians may encounter different usability issues. Sub-task analysis enabled to recognize these subtle usability issues, workflow, and navigation pattern variability that would have otherwise been unnoticed.

Thematic analysis was employed to analyze our data and categorize our findings (1). Some themes used in this study were adopted from a study by Walji et al (91) but were supplemented with additional themes for a more granular analysis. The two themes adopted from Walji et al., were: interface and terminology. Five themes emerged from our data analysis: inconsistencies, user interface issues, structured data issues, ambiguous terminologies, and workarounds. The usability issues identified were also rated on five-point severity scale based on a National Institute of Standards and Technology report Severity ratings were: 4) Catastrophic: Potential for patient mortality, 3) Major: Potential for patient morbidity, 2) Moderate: Potential for workarounds that create patient safety risks, 1) Minor: Potential for lower quality of clinical care due to decreased efficiency, increased frustration, or increased documentation burden or workload burden, and 0) No Issue / Not applicable. An investigator who is an experienced physician champion (JLB) reviewed severity ratings. He was the founding chair of the HIMSS usability task force and knowledgeable in assessment of EHR usability (95).

Human Subjects

This is an experimental trial using physicians and artificial patient cases in the clinical application. No real patients or patient information is necessary. The physicians' identifications were masked with pseudo names throughout the study.

Gender/Minority Mix

Due to the small number of physicians (30) and limited pool of potential physicians, no specific requirements for minority or gender enrollment were applied.

Participants

Table 2 shows the demographics of 6 expert resident physicians and 10 novice primary care physicians that participated in the usability test presented as percentages. Examined demographics include gender, age, race, and use of EHR. Two expert resident physicians did not provide information on their date of birth and EHR experience and was excluded in the calculation of age range, mean age, and EHR experience. In round 1, out of ten novice resident physicians, seven were from family medicine and three were from internal medicine. In round 2, out of eight novice resident physicians, five were from family medicine and three were from internal medicine. Two expert resident physicians did not provide information on their date of birth and EHR experience and was excluded in the calculation of age range, mean age, and EHR experience. Because of the small sample size for this type of study, we did not attempt to control for age or gender.

Table 2 Demographics of 6 expert resident physicians and 10 novice primary care physicians that participated in the usability test presented as percentages. Examined demographics include gender, age, race, and use of EHR.

Demographics	**Round 1**		**Round 2**	
	Novice	Expert	Novice	Expert
Gender				
Male	6 (60%)	1 (17%)	5 (63%)	0 (0%)
Female	4 (40%)	5 (83%)	3 (38%)	4 (100%)
Age (mean)	28 years	31 years	29 years	32 years
Race/Ethnicity				
Black	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Asian	1 (10%)	0 (0%)	1 (19%)	0 (0%)
White	9 (90%)	6 (100%)	7 (81%)	4 (100%)

American Indian/Alaskan Native	0	(0%)	0	(0%)	0	(0%)	0	(0%)
Pacific Islander	0	(0%)	0	(0%)	0	(0%)	0	(0%)
Experience other than current EHR								
None	4	(40%)	1	(17%)	3	(38%)	1	(25%)
Less than 3 months	2	(20%)	0	(0%)	2	(25%)	0	(0%)
3 months – 6 months	0	(0%)	0	(0%)	0	(0%)	0	(0%)
7 months – 1 year	1	(10%)	1	(17%)	1	(13%)	1	(25%)
Over 2 years	3	(30%)	2	(33%)	2	(25%)	2	(50%)

In round 3, out of nine first year resident physicians, four were from family medicine and five were from internal medicine. Table 3 shows the demographics of primary care resident physicians that participated in the third round of usability test presented as percentages. Examined demographics include: gender, age, race, and Experience with EHR other than current EHR. Other ratings examined were:

- Your skill level when using a computer
- I am confident when using this EHR
- Satisfaction with documenting in this EHR
- Satisfaction with creating orders in this EHR
- Satisfaction with seeking information in this EHR
- Satisfaction with reading notes in this EHR

One second year resident physician did not provide information on their date of birth and was excluded in the calculation of age range experience. Another second year resident physician did not provide information on their skill level and confidence while using the EHR and satisfaction completing tasks within the EHR and was excluded in these calculations.

Table 3 Demographics of 9 first year resident physicians, 8 second year resident physicians, and 12 third year resident physicians that participated in round 3 of the usability test presented as percentages. Examined demographics include gender, age, race, and use of EHR.

Demographics	**Year 1**		**Year 2**		**Year 3**	
Gender						
Male	4	44%	5	63%	4	33%
Female	5	56%	3	38%	8	67%
Age (mean)	30 years		29 years		30 years	
Race/Ethnicity						
Black	0	0%	0	0%	0	0%
Asian	2	22%	3	38%	1	8%
White	7	78%	5	63%	11	92%
American Indian/Alaskan Native	0	0%	0	0%	0	0%
Pacific Islander	0	0%	0	0%	0	0%
Experience other than current EHR						
None	2	22%	4	50%	8	67%
Less than 3 months	2	22%	1	13%	0	0%
3 months – 6 months	1	11%	0	0%	0	0%
7 months – 1 year	2	22%	2	25%	2	17%
Over 2 years	2	22%	1	13%	2	17%
What is your skill level when using a computer?						
Do not use	0	0%	0	0%	0	0%
Very Unskilled	0	0%	0	0%	0	0%
Unskilled	0	0%	0	0%	1	8%
Skilled	9	100%	7	88%	9	75%
Very Skilled	0	0%	1	13%	2	17%
I am confident when using this EHR						
Not at all	0	0%	0	0%	0	0%
Slightly	1	11%	0	0%	0	0%
Moderately	5	56%	2	25%	5	42%
Very	3	33%	5	63%	6	50%
Extremely	0	0%	1	13%	1	8%
Satisfaction with documenting in this EHR						
Not satisfied	0	0%	0	0%	0	0%
Slightly satisfied	2	22%	0	0%	0	0%
Moderately satisfied	4	44%	3	38%	8	67%
Very satisfied	3	33%	4	50%	4	33%
Extremely satisfied	0	0%	1	13%	0	0%

Satisfaction with creating orders in this EHR						
Not satisfied	0	0%	0	0%	1	8%
Slightly satisfied	2	22%	0	0%	0	0%
Moderately satisfied	4	44%	3	38%	7	58%
Very satisfied	3	33%	4	50%	4	33%
Extremely satisfied	0	0%	1	13%	0	0%
Satisfaction with seeking information in this EHR						
Not satisfied	0	0%	0	0%	0	0%
Slightly satisfied	2	22%	0	0%	2	17%
Moderately satisfied	5	56%	3	38%	8	67%
Very satisfied	2	22%	3	38%	2	17%
Extremely satisfied	0	0%	2	25%	0	0%
Satisfaction with reading notes in this EHR						
Not satisfied	0	0%	0	0%	0	0%
Slightly satisfied	0	0%	0	0%	0	0%
Moderately satisfied	3	33%	1	13%	7	58%
Very satisfied	6	67%	5	63%	3	25%
Extremely satisfied	0	0%	2	25%	2	17%

Performance Measures of physicians by clinical year (Year 1, Year 2, Year 3)

Percent Task Success Rate

Geometric mean values of percent task success rates were compared between the physicians by clinical year: year 1 (Y1), year 2 (Y2), and year 3 (Y3) (Figure 2) (88). There was a 3 percent point increase in physicians' percent task success rate between year 1 and year 2 (Y1: 95%, CI [90%, 100%]; Y2: 98% CI [90%, 100%]). There was a 3 percent point decrease in physicians' percent task success rate between year 2 (Y2: 98%, CI [90%, 100%]; Y3: 95% CI [90%, 100%]) and year 3. From year 1 to year 3 there was only a 0 percent point increase in physicians' percent task success rate. Resident physicians from all three years had the same task success in eight tasks: 1, 4 – 6, 11, 12, 14, 18, and 19. Second year resident physicians group achieved higher success rate in two tasks: 8 and 17; and third year resident physicians had highest task success in task 16. First year resident had the lowest task success in six out of nineteen tasks: 2, 3, 7, 9, 13, and 16 while third year residents had the lowest task success in four out of nineteen tasks: task: 8, 10, 15, and 17.

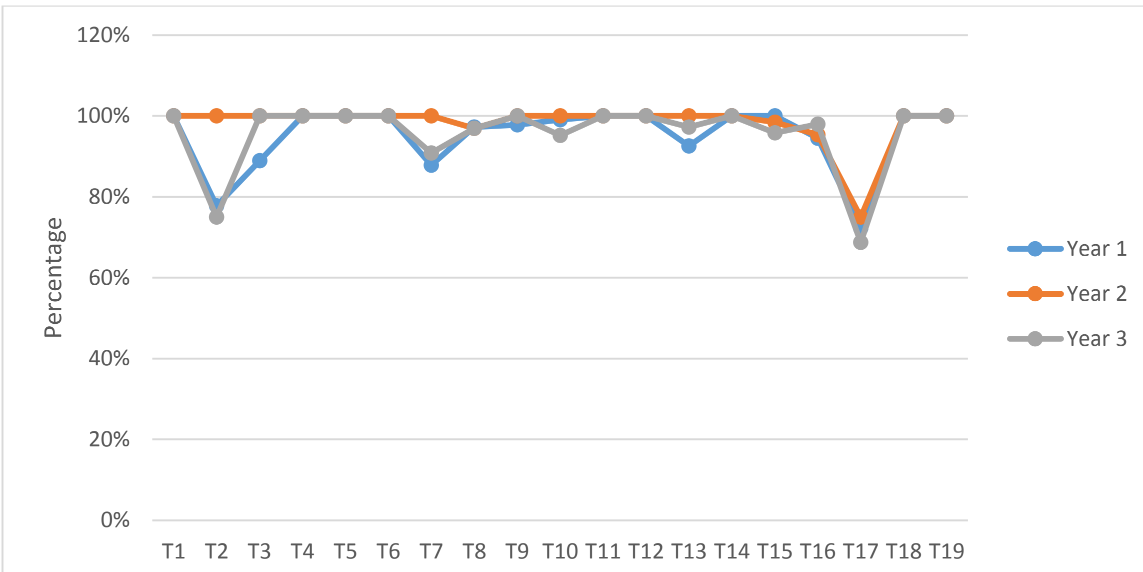

Figure 2 Geometric mean values of percent task success rates were compared between the physicians by clinical year: year 1 (Y1), year 2 (Y2), and year 3 (Y3). There was a 3 percent point increase in physicians' percent task success rate between year 1 and year 2 (Y1: 95%, CI [90%, 100%]; Y2: 98% CI [90%, 100%]). There was a 3 percent point decrease in physicians' percent task success rate between year 2 (Y2: 98%, CI [90%, 100%]; Y3: 95% CI [90%, 100%]) and year 3. From year 1 to year 3 there was only a 0 percent point increase in physicians' percent task success rate. T = task.

Time on Task (TOT)

Geometric mean values of time-on-task (TOT) were compared between physicians by clinical year: year 1, year 2, and year 3 (Figure 3). There was a 5% decrease in physicians' time on task between year 1 and year 2 (Y1: 38s CI [28s, 52s], Y2: 36s CI [25s, 52s]). However, there was a 6% increase in physicians' time on task between year 2 and year 3 (Y2: 36s CI [25s, 52s], Y3: 38s CI [28s, 53s]). From year 1 to year 3 there was only no increase in physicians' time on task. First year resident physicians took less time completing five out of nineteen tasks (tasks 1, 4, 13, 17, and 18) than second and third year resident. Second year resident physicians took less time completing eight out of nineteen tasks (tasks 2, 5, 6, 7, 8, 10, 12, and 16) than first and third year resident physicians and the same time as third year resident physicians when completing task 3. Third year resident physicians took less time completing five out of nineteen tasks: (tasks 9, 11, 14, 15, and 19) than first and second year resident physicians. First and second year residents spent the longest time completing seven out of nineteen tasks, and third year resident physicians spent the longest time completing five out of nineteen tasks. First and second year resident physicians spent the most time completing task 10: Include Physical exam (Y1: 112s, Y2: 94s) and third year resident physicians spent the most time completing task 10: 7: Document and new medication allergy. Resident physicians from all three years spent the least amount of time on task 12: Save the note (Y1: 9s, Y2: 7s, Y3: 8s).

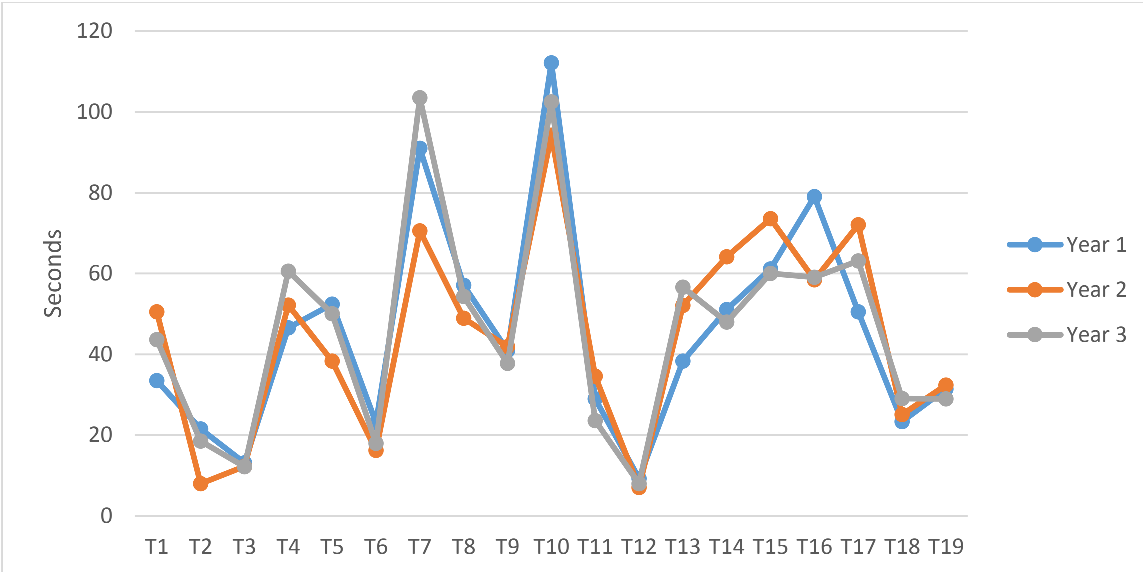

Figure 3 Geometric mean values of time-on-task of nineteen tasks between resident physicians by clinical year: year 1, year 2, and year 3. A lower number of seconds usually indicate higher performance and higher number of seconds usually indicate lower performance for time on task. There was a 5% decrease in physicians' time on task between year 1 and year 2 (Y1: 38s CI [28s, 52s], Y2: 36s CI [25s, 52s]). However, there was a 6% increase in physicians' time on task between year 2 and year 3 (Y2: 36s CI [25s, 52s], Y3: 38s CI [28s, 53s]). From year 1 to year 3 there was only no increase in physicians' time on task. T = task.

Mouse Clicks

Geometric mean values of mouse clicks were compared between the three physician groups: year 1, 2, and 3 (Figure 4). There was a 13% decrease in physicians' mouse clicks between year 1 and year 2 (Y1: 8 clicks CI [5 clicks, 13 clicks], Y2: 7 clicks CI [4 clicks, 12 clicks]). There was a 14% increase in physicians' mouse clicks between year 2 and year 3 (Y2: 7 clicks CI [4 clicks, 12 clicks], Y3: 8 clicks CI [6clicks, 12 clicks]). From year 1 to year 3 there was no improvement in physicians' mouse clicks. Year 2 resident physicians completed the tasks with slightly fewer mouse clicks than first and third year resident physicians (Y1: 8 clicks, Y2: 7 clicks, Y3: 8 clicks). First year resident physicians achieved fewer mouse clicks in five tasks (tasks: 1, 3, 13, 17, and 18) than second and third year residents. Second year resident physicians had fewer mouse clicks than first and third year residents in seven tasks (tasks 2, 4, 5, 6, 8, 10, and 16) than first and third year resident physicians. Third year resident physicians had fewer mouse clicks than first and second year residents in four tasks: , 11, 14, 15, and 19. First and second year resident physicians had the same number of clicks in two tasks: 14 and 19. Second and third year residents had the same number of clicks in four tasks: tasks 1, 3, 7, and 18. First and third year resident physicians had the same number of tasks in three tasks: tasks: 4, 8, and 9. Physicians of all years had the same number of mouse clicks for task 12. First year residents had the most mouse clicks for ten tasks, followed by second year resident physicians with six tasks, and third year resident physicians with three tasks. Second year residents had the most mouse clicks for seven out of nineteen tasks, followed by first year resident physicians with five out of nineteen tasks, and third year resident physicians with one out of nineteen tasks. First year resident physicians had the most mouse clicks completing Task 10: Include Physical exam (33 clicks), year two residents had the most mouse clicks when completing task 15: Place order for basic metabolic panel (BMP) (27 clicks). Year three resident physicians had the most mouse clicks when completing task 7: Document new medication allergy (21 clicks). Year one and year three resident physicians had the shortest mouse clicks (2 clicks) when completing Task 3: Include Chief Complaint, task 4: Include History of Present Illness, task 6: Review problem list contained in the note, and task 12: Save the note Year two residents had the shortest mouse clicks (1 click) when completing task 4: Include History of Present Illness and task 6: Review problem list contained in the note.

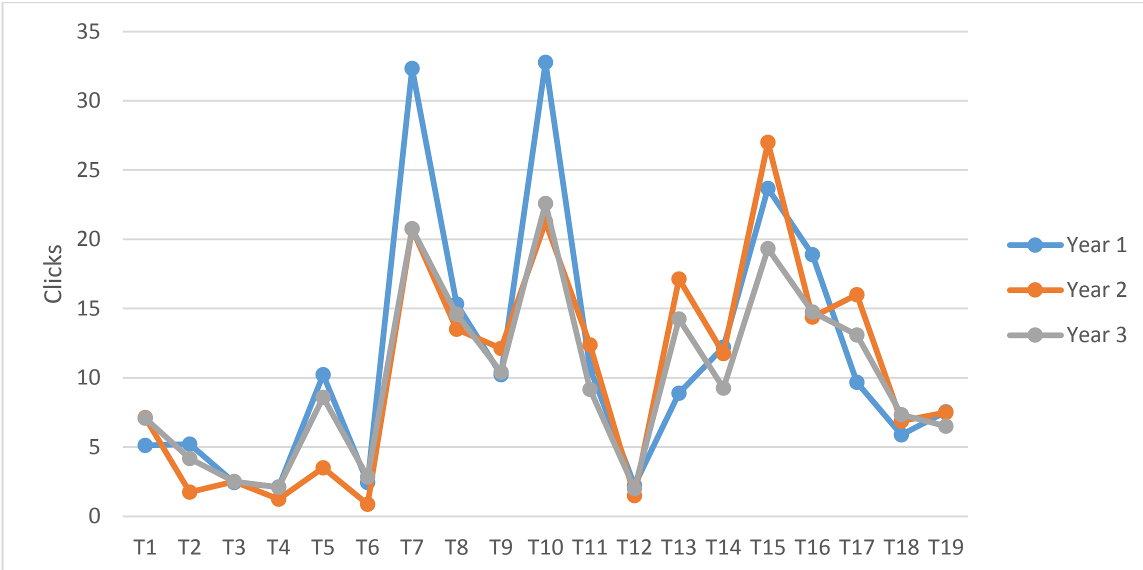

Figure 4 Geometric mean values of mouse clicks were compared between the three physician groups (year 1, 2, and 3). A lower number of mouse clicks usually indicate higher performance and higher mouse clicks usually indicate lower performance for mouse clicks. There was a 13% decrease in physicians' mouse clicks between year 1 and year 2 (Y1: 8 clicks CI [5 clicks, 13 clicks], Y2: 7 clicks CI [4 clicks, 12 clicks]). There was a 14% increase in physicians' mouse clicks between year 2 and year 3 (Y2: 7 clicks CI [4 clicks, 12 clicks], Y3: 8 clicks CI [6clicks, 12 clicks]). From year 1 to year 3 there was no improvement in physicians' mouse clicks. T = task.

Mouse Movements

Geometric mean values of mouse movement, length of the navigation path to complete a given task, were compared between three physician groups: year 1, 2, and 3 (Figure 5). There was a 7% decrease in physicians' mouse movements from year 1 to year 2 (Y1: 8,480 pixels CI [6,273 pixels, 11,462 pixels], Y2: 7,856 pixels CI [5,380 pixels, 11,471 pixels]). There was a 6% increase in physicians' mouse movements from year 2 to year 3 (Y2: 7,856 pixels CI [5,380 pixels, 11,471 pixels], Y3: 8,319pixels CI [6,101 pixels, 11,343 pixels]). From year 1 to year 3 there was a 2% decrease in physicians' mouse movements (Y1: 8,480 pixels CI [6,273 pixels, 11,462 pixels], Y3: 8,319pixels CI [6,101 pixels, 11,343 pixels]). Overall, second year resident physicians showed slightly shorter mouse movements than first and third year resident physicians across the nineteen tasks (Y1: 8,480 pixels, Y2: 7,856, Y3: 8,319 pixels). The first year resident physicians showed shorter mouse movements in four of nineteen tasks: tasks 1, 13, 17, and 18. Second year resident physicians showed shorter mouse movements in eight tasks: tasks 2, 4, 5, 7, 8, 10, 13, and 16. Third year resident physicians also showed shorter mouse movements in six tasks: tasks: 6, 9, 11, 14, 15, and 19. First year residents had the longest mouse movement for eight out of nineteen tasks, followed by second year resident physicians with six out of nineteen tasks, and third year resident physicians with five out of nineteen tasks. Year one and year three resident physicians spent most of the mouse movements completing Task 7: Document new medication allergy (Y1: 25,346 pixels, Y3: 22, 633 pixels). Year two residents had the longest mouse movement when completing task 15: Place order for basic metabolic panel (BMP) (Y2: 22,380 pixels). Year one and year three resident physicians had the shortest mouse movements when completing Task 3: Include Chief Complaint (Y1: 2,532 pixels, Y3: 2,672 pixels). Year two residents had the shortest mouse movement when completing task 2: Include visit information (Y2: 1,663 pixels).

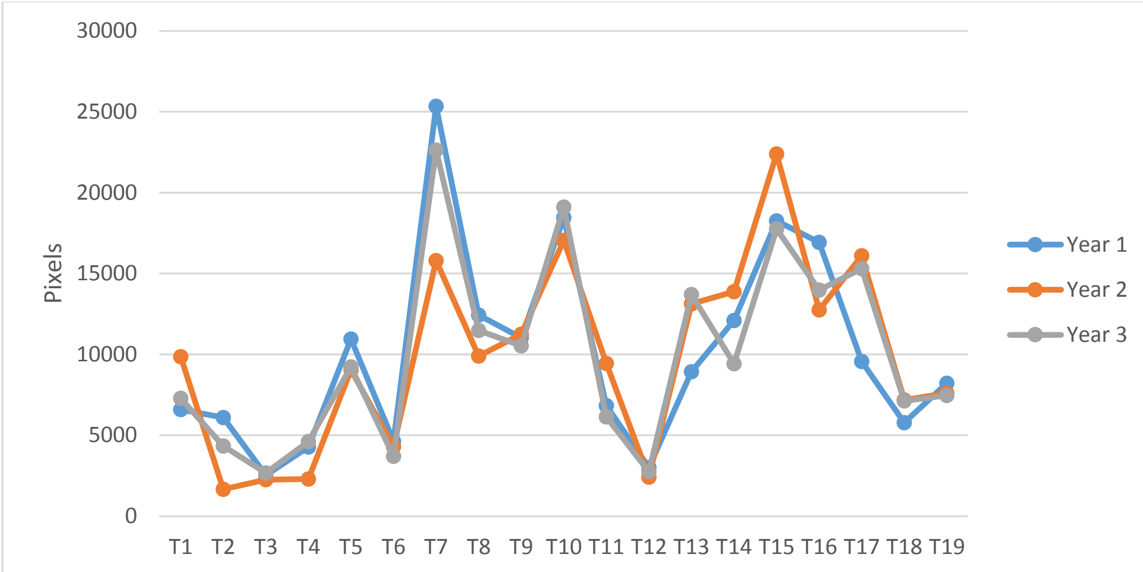

Figure 5 Geometric mean values of mouse movement, length of the navigation path to complete a given task, were compared between three physician groups: year 1, 2, and 3. There was a 7% decrease in physicians' mouse movements from year 1 to year 2 (Y1: 8,480 pixels CI [6,273 pixels, 11,462 pixels], Y2: 7,856 pixels CI [5,380 pixels, 11,471 pixels]). There was a 6% increase in physicians' mouse movements from year 2 to year 3 (Y2: 7,856 pixels CI [5,380 pixels, 11,471 pixels], Y3: 8,319pixels CI [6,101 pixels, 11,343 pixels]). From year 1 to year 3 there was a 2% decrease in physicians' mouse movements (Y1: 8,480 pixels CI [6,273 pixels, 11,462 pixels], Y3: 8,319pixels CI [6,101 pixels, 11,343 pixels]). T = task.

Performance Measures of novice and expert resident physicians by 3 rounds of data collection (round 1 (R1), round 2 (R2), round 3 (R3)).

Percent Task Success Rate

Geometric mean values of percent task success rates were compared between the two physician groups across three rounds (Figure 6) (88). There was a 6 percent point increase in novice physician group's percent task success rate between round 1 and round 2 (R1: 92%, CI [90%, 100%]; R2: 98%, CI [90%, 100%]). There was a 3 percent point decrease in novice physician group's percent task success rate between round 2 and round 3 (R2: 98%, CI [90%, 100%]; R3: 95%, CI [90%, 100%]). There was a 3 percent point increase in novice physician group's percent task success rate between round 1 and round 3 (R1: 92%, CI [90%, 100%]; R3: 95% CI [90%, 100%]).

Similarly, expert resident physicians had a 7 percent point increase in percent task success rate between round 1 (90%, CI [90%, 100%]; 97%; CI [90%, 100%]). There was a 1 percent point decrease in expert resident physician group's percent task success rate between round 2 and round 3 (R2: 97%, CI [90%, 100%]; R3: 96%, CI [90%, 100%]). There was a 6 percent point increase in expert resident physician group's percent task success rate between round 1 and round 3 (R1: 90%, CI [90%, 100%]; R2: 96%, CI [90%, 100%]).

When novice and expert resident physicians' task success rate were compared in round 1, the percentage difference between novice and expert resident physicians' task success was 5%. When novice and expert resident physicians' task success rate were compared in round 2, the percentage difference between novice and expert resident physicians' task success was also 5%. When novice and expert resident physicians' task success rate were compared in round 3, the percentage difference between novice and expert resident physicians' task success was 2%.

When task success rates were compared between the physician groups, novice physician group had higher task success rate than the expert resident physician group did in round 1 (novice 92%, expert 90%) and round 2 (novice 98%, expert 97%) but expert resident physicians had higher task success rate than the novice physician in round three (novice 95%, expert 96%). In round 1, novice physician group achieved higher success rate than expert resident physicians in seven tasks: 2, 8, 11, 13, and 15 – 17; the same success rate in seven tasks: 1, 3 – 6, 9, and 19, and lower success rate in five tasks: 7, 10, 12, 14, and 18. In round 2, novice resident physician group achieved higher success rate than expert resident physicians in three tasks: 8, 9, and 14; the same success rate in fifteen tasks: 1 – 7, 10 – 13, and 16 – 19; and lower success rate in task 15. In round 3, novice resident physician group achieved higher success rate in three tasks: 10, 15, and 17; the same success rate in ten tasks: 1, 4 – 6, 11, 12, 14, 18, and 19; and lower success rate in six tasks: 2, 3, 7, 9, 13, and 16. Both novice and expert resident physician groups had the lowest task success for task 17: Add a medication to your favorites list in round 1 (50%, expert group vs. 60%, novice group). In round 2 (75%, expert group vs. 75%, novice group) novice resident physicians increased their task success by 25% and expert resident physicians increased their tasks success by 50%. However, from round 2 to round 3, task success for task 17 (71%, expert group vs. 72%, novice group) decreased by 3% for novice resident physicians and by 4% for expert resident physicians. In round 1, one novice physician was not able to order a chest x-ray for Task 14: Place order for chest x-ray and did not understand the meaning of the alert that was brought up during the task. This resident was the only participant that received the alert, “Radiology orders should be placed following downtime procedures during 2200 and 0000.” This message meant that there was going to be an update to the system and so all orders would have to be processed using paper. If a physician received this error during clinical workflow, the physician would not be able to order the chest X-ray at that moment and may have to get back to it later. The physician may then forget to order the X-ray and may miss an important diagnosis that could have been found from the patient receiving the X-ray. This alert did not show up in round one and round 2.

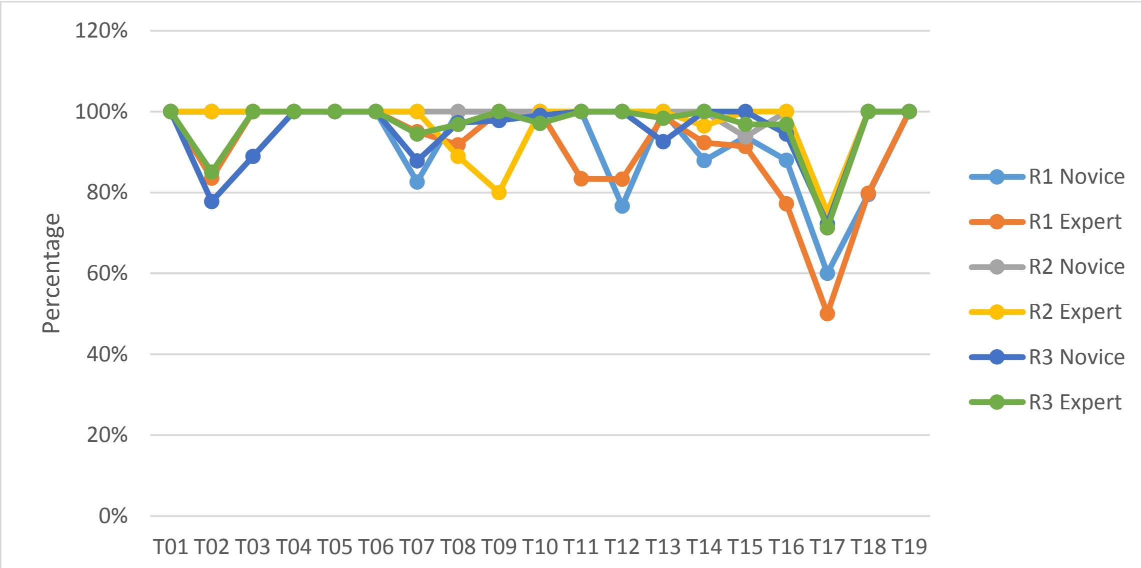

Figure 6 Geometric mean values of percent task success rates were compared between the two physician groups across three rounds. There was a 6 percent point increase in novice physician group's percent task success rate between round 1 and round 2 (R1: 92%, CI [90%, 100%]; R2: 98%, CI [90%, 100%]). There was a 3 percent point decrease in novice physician group's percent task success rate between round 2 and round 3 (R2: 98%, CI [90%, 100%]; R3: 95%, CI [90%, 100%]). There was a 3 percent point increase in novice physician group's percent task success rate between round 1 and round 3 (R1: 92%, CI [90%, 100%]; R3: 95% CI [90%, 100%]). Expert resident physicians had a 7 percent point increase in percent task success rate between round 1 (90%, CI [90%, 100%]; 97%; CI [90%, 100%]). There was a 1 percent point decrease in expert resident physician group's percent task success rate between round 2 and round 3 (R2: 97%, CI [90%, 100%]; R3: 96%, CI [90%, 100%]). There was a 6 percent point increase in expert resident physician group's percent task success rate between round 1 and round 3 (R1: 90%, CI [90%, 100%]; R2: 96%, CI [90%, 100%]). T = task.

Time on Task (TOT)

Geometric mean values of time-on-task (TOT) were compared between the two physician groups across three rounds (Figure 7). There was a 9% decrease in novice resident physicians' time on task between round 1 and round 2 (R1: 44s CI [32s, 62s], R2: 40s CI [27s, 59s]). There was a 5% decrease in novice resident physicians' time on task between round 2 and round 3 (R2: 40s CI [27s, 59s], R3: 38s CI [28, 52]). There was a 14% decrease in novice resident physicians' time on task between round 1 and round 3 (R1: 44s CI [32s, 62s], R3: 38s CI [28s, 52s]).

There was a 21% decrease in expert resident physician group's time on task between round 1 and round 2 (R1: 39s CI [29s, 51s], R2: 31s CI [22s, 42s]). There was a 26% increase in expert resident physicians' time on task between round 2 and round 3 (R2: 31s CI [22s, 42s], R3: 39s CI [28s, 54s]). There was no improvement in expert resident physicians' time on task between round 1 and round 3 (R1: 39s CI [32s, 62s], R3: 39s CI [28s, 54s]). When time on task was compared between the physician groups, overall novice physician group (R1: 44s, R2: 40s, R3: 38s) spent more time completing the tasks in round 1 and round 2 compared to the expert resident physician group (R1: 39s, R2: 31s, R3: 39s). However in round 3, novice resident physicians spent a little less time completing tasks than expert resident physicians (novice 38s, expert 39s). In round 1, novice physician group spent less time than expert resident physicians completing seven out of nineteen tasks: 2, 3, 5, 6, 11, 12, and 19. In round 2, novice physician group spent less time completing three out of nineteen tasks: 2,11, and 12 and the same time completing tasks 6 and 18.In round 3, novice physician group spent less time completing nine out of nineteen tasks: 1, 3, 4, 11, 13, 14, 15, 17, and 18 than expert resident physicians.

When novice and expert resident physicians' time on task were compared in round 1, the percentage difference between novice and expert resident physicians' time on task was 12%. When novice and expert resident physicians' time on task were compared in round 2, the percentage difference between novice and expert resident physicians' time on task was 25%. When novice and expert resident physicians' time on task were compared in round 3, the percentage difference between novice and expert resident physicians' time on task was 3%.

In round 1, both physician groups had the longest time spent on task 7: Document new medication allergy. However, in round 2 time on task for task 7 decreased by 45% for expert resident physician group (R1: 97s, R2: 53s) and 35% for novice physician group (R1: 148s, R2: 96s). From round 2 to round 3, time on task for task 7 increased by 68% for expert resident physicians and decreased by 5% for novice resident physicians. In round 2 and round 3, novice resident physicians spent the most time completing task 14: Place order for chest X-ray in round 2 and task 10: Include Physical exam in round three. Expert resident physicians spent the most time completing task 10: Include Physical exam.

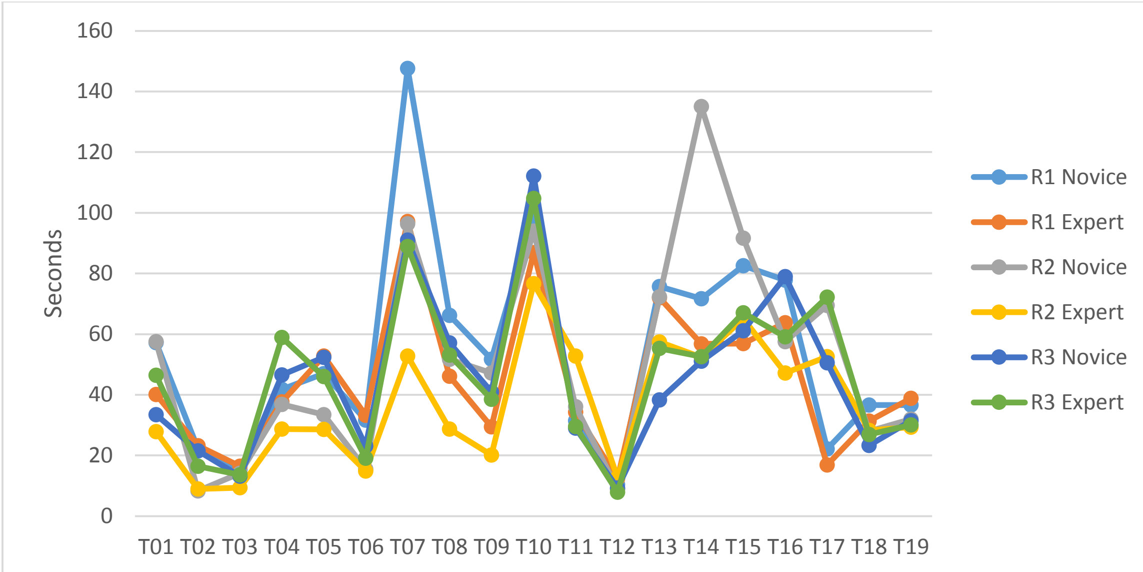

Figure 7 Geometric mean values of time-on-task (TOT) were compared between the two physician groups across three rounds. There was a 9% decrease in novice resident physicians' time on task between round 1 and round 2 (R1: 44s CI [32s, 62s], R2: 40s CI [27s, 59s]). There was a 5% decrease in novice resident physicians' time on task between round 2 and round 3 (R2: 40s CI [27s, 59s], R3: 38s CI [28, 52]). There was a 14% decrease in novice resident physicians' time on task between round 1 and round 3 (R1: 44s CI [32s, 62s], R3: 38s CI [28s, 52s]). There was a 21% decrease in expert resident physician group's time on task between round 1 and round 2 (R1: 39s CI [29s, 51s], R2: 31s CI [22s, 42s]). There was a 26% increase in expert resident physicians' time on task between round 2 and round 3 (R2: 31s CI [22s, 42s], R3: 39s CI [28s, 54s]). There was no improvement in expert resident physicians' time on task between round 1 and round 3 (R1: 39s CI [32s, 62s], R3: 39s CI [28s, 54s]). T = task.

Mouse Clicks

Geometric mean values of mouse clicks were compared between the two physician groups across three rounds (Figure 8). There was a 25% decrease in novice resident physicians' mouse clicks between round 1 and round 2 (R1: 8 clicks CI [6 clicks, 13 clicks], R2: 6 clicks CI [4 clicks, 11 clicks]). There was a 33% increase in novice resident physicians' mouse clicks between round 2 and round 3 (R2: 6 clicks CI [4 clicks, 11 clicks], R3: 8 clicks CI [5 clicks, 13 clicks]). There was no improvement in novice resident physicians' mouse clicks between round 1 and round 3 (R1: 8 clicks CI [6 clicks, 13 clicks], R2: 8 clicks CI [4 clicks, 11 clicks]).

Similarly, there was a 25% decrease in expert resident physicians' mouse clicks between round 1 and round 2 (R1: 8 clicks CI [5 clicks, 11 clicks], R2: 6 clicks, 95% CI [1 clicks, 11 clicks]). There was a 33% increase in expert resident physicians' mouse clicks between round 2 and round 3 (R2: 6 clicks CI [1 clicks, 11 clicks], R3: 8 clicks, CI [5 clicks, 12 clicks]). There was no improvement in expert resident physicians' mouse clicks between round 1 and round 3 (R1: 8 clicks CI [5 clicks, 11 clicks], R3: 8 clicks CI [5 clicks, 12 clicks]).

When novice and expert resident physicians' mouse clicks were compared in all three rounds, the percentage difference between novice and expert resident physicians' mouse clicks was no change (0%).

When mouse clicks were compared between the physician groups, novice physician group completed the tasks with the same number of tasks as expert resident physicians in round 1 (8 clicks), round 2 (6 clicks), and round three (8 clicks). In round 1, the novice physician group achieved lower mouse clicks than expert resident physician group in five tasks: 6, 8, 11, 13, and 19; higher mouse clicks in eleven tasks: 1, 3, 5, 7, 9 10, and 14 – 18; and comparable number of clicks in three tasks: 2, 4, and 12. In round 2, novice resident physicians used less mouse clicks completing four tasks: 10, 11, 18 and 19; the same number of clicks completing five tasks: 2, 4, 8, 12, and 16; and more clicks completing ten tasks: 1, 3, 5, 6, 7, 9, 13, 14, 15, and 17. In round 3, novice resident physicians used less mouse clicks completing six tasks: 1, 3, 9, 13, 17, and 18; the same number of clicks completing three tasks: 4, 6, and 12; and more clicks completing ten tasks: 2, 5, 7, 8, 10, 11, 14, 15, 16, and 19. In round 1, both novice and expert resident physicians had the highest number of mouse clicks out of all tasks when completing task 7: Add a medication to your favorites list. However, in round 2, the task with the highest number of mouse clicks by expert resident physicians changed from task 7 to task 15: Place order for basic metabolic panel (BMP) and novice resident physicians had the highest mouse clicks when completing task 14: Place order for chest X-ray in round 2 compared to task 7 in round 1. In round 3, task 10: Include Physical exam and task 15: Place order for basic metabolic panel (BMP) remained expert resident physicians' task with the most number of mouse clicks. Novice resident physicians' also had the most mouse clicks when completing task 10: Include Physical exam in round 3.

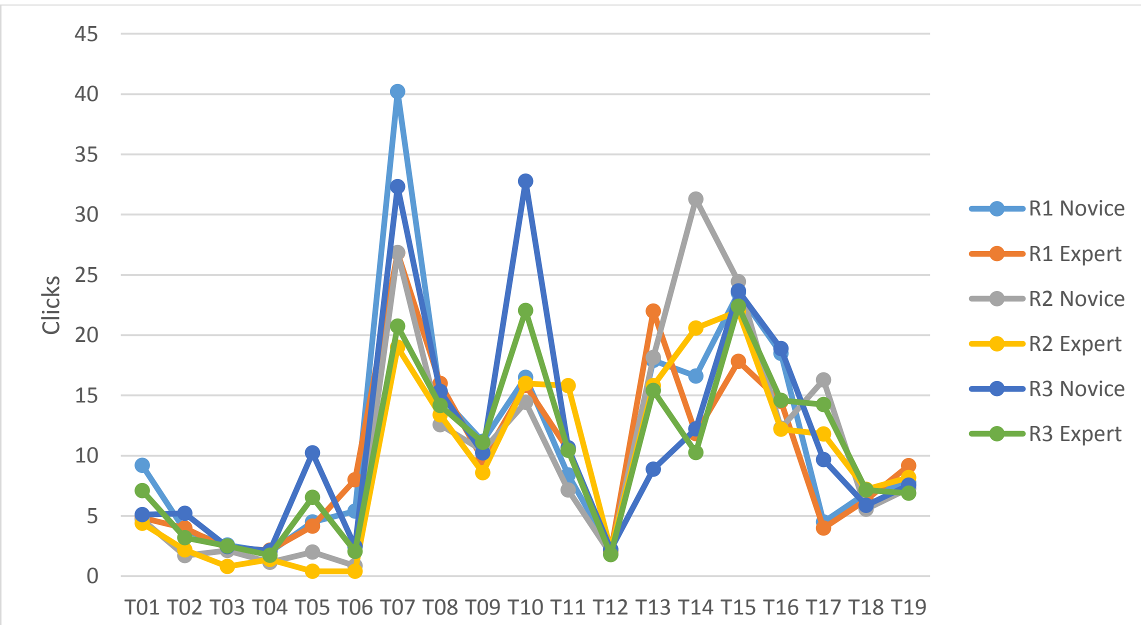

Figure 8 Geometric mean values of mouse clicks were compared between the two physician groups across three rounds. There was a 25% decrease in novice resident physicians' mouse clicks between round 1 and round 2 (R1: 8 clicks CI [6 clicks, 13 clicks], R2: 6 clicks CI [4 clicks, 11 clicks]). There was a 33% increase in novice resident physicians' mouse clicks between round 2 and round 3 (R2: 6 clicks CI [4 clicks, 11 clicks], R3: 8 clicks CI [5 clicks, 13 clicks]). There was no improvement in novice resident physicians' mouse clicks between round 1 and round 3 (R1: 8 clicks

CI [6 clicks, 13 clicks], R2: 8 clicks CI [4 clicks, 11 clicks]). Similarly, there was a 25% decrease in expert resident physicians' mouse clicks between round 1 and round 2 (R1: 8 clicks CI [5 clicks, 11 clicks], R2: 6 clicks, 95% CI [1 clicks, 11 clicks]). There was a 33% increase in expert resident physicians' mouse clicks between round 2 and round 3 (R2: 6 clicks CI [1 clicks, 11 clicks], R3: 8 clicks, CI [5 clicks, 12 clicks]). There was no improvement in expert resident physicians' mouse clicks between round 1 and round 3 (R1: 8 clicks CI [5 clicks, 11 clicks], R3: 8 clicks CI [5 clicks, 12 clicks]).

Mouse Movements

Geometric mean values of mouse movement, length of the navigation path to complete a given task, were compared between two physician groups across three rounds (Figure 9). There was a 14% decrease in novice resident physicians' mouse movements between round 1 and round 2 (R1: 9,247 pixels CI [6,404 pixels, 13,353 pixels], R2: 7,992 pixels CI [5,350 pixels, 11,936 pixels]). There was a 6% increase in novice resident physicians' mouse movements between round 2 and round 3 (R2: 7,992 pixels CI [5,350 pixels, 11,936 pixels], R3: 8,480 pixels CI [6,273, 11,462]). There was an 8% decrease in novice resident physicians' mouse movements between round 1 and round 3 (R1: 9,247 pixels CI [6,404 pixels, 13,353 pixels], R3: 8,480 pixels CI [6,273, 11,462]).

There was also a 14% decrease in expert resident physicians' mouse movements between round 1 and round 2 (R1: 7,325 CI [5,237 pixels, 10,247 pixels], R2: 6,329 pixels, CI [4,299 pixels, 9,317 pixels]). There was a 30% increase in expert resident physicians' mouse movements between round 2 and round 3 (R2: 6,329 CI [4,299 pixels, 9,317 pixels], R3: 8,235 pixels CI [5,953 pixels, 11,392 pixels]). There was a 12% increase in expert resident physicians' mouse movements between round 1 and round 3 (R1: 7,325 CI [5,237 pixels, 10,247 pixels], R3: 8,235 pixels CI [5,953 pixels, 11,392 pixels]).

When novice and expert resident physicians' mouse movements were compared in round 1, the percentage difference between novice and expert resident physicians' mouse movements was 23%. When novice and expert resident physicians' mouse movements were compared in round 2, the percentage difference between novice and expert resident physicians' mouse movements was also 23%. When novice and expert resident physicians' mouse movements were compared in round 3, the percentage difference between novice and expert resident physicians' mouse movements was 3%.

When mouse movements were compared between the physician groups, the novice resident physicians (R1: 9,247 pixels, R2: 7,992 pixels, R3: 8,480 pixels) showed slightly longer mouse movements than expert resident physicians (R1: 7,325 pixels, R2: 6,329 pixels, R3: 8,005 pixels) did across all three rounds. In round 1, the novice resident physicians showed longer mouse movements than expert resident physicians in fifteen of nineteen tasks: tasks 1, 2, 4, 5, 7 – 12, and 14 – 18; and shorter mouse movements in four tasks: 3, 6, 13, and 19. In round 2, novice resident physicians used shorter mouse movements than expert resident physicians when completing seven out of nineteen tasks: 2, 10 – 13, 18, and 19 and used more movements completing twelve tasks: 1, 3, 4, 5 – 9, and 14 – 17. In round 3, novice resident physicians again used shorter mouse movements in completing six out of nineteen tasks: 1, 11, 13, 15, 17, and 18; and used more movements completing twelve tasks: 2 – 8, 10, 12, 14, 16, and 19. In round 1, novice and expert resident physicians had the longest mouse movement out of all tasks when completing task 7: Add a medication to your favorites list (novice: 35,942 pixels, expert: 20,770 pixels). In round 2, the task with the longest mouse movements by novice resident physicians was task 14: Place order for chest X-ray (27,792) compared and expert resident physicians had the longest mouse movements when completing task 15: Place order for basic metabolic panel (BMP) (18,471 pixels). In round three, novice and expert resident physicians again had the longest mouse movement out of all tasks when completing task 7: Add a medication to your favorites list (novice: 25,346 pixels, expert: 19,902 pixels).

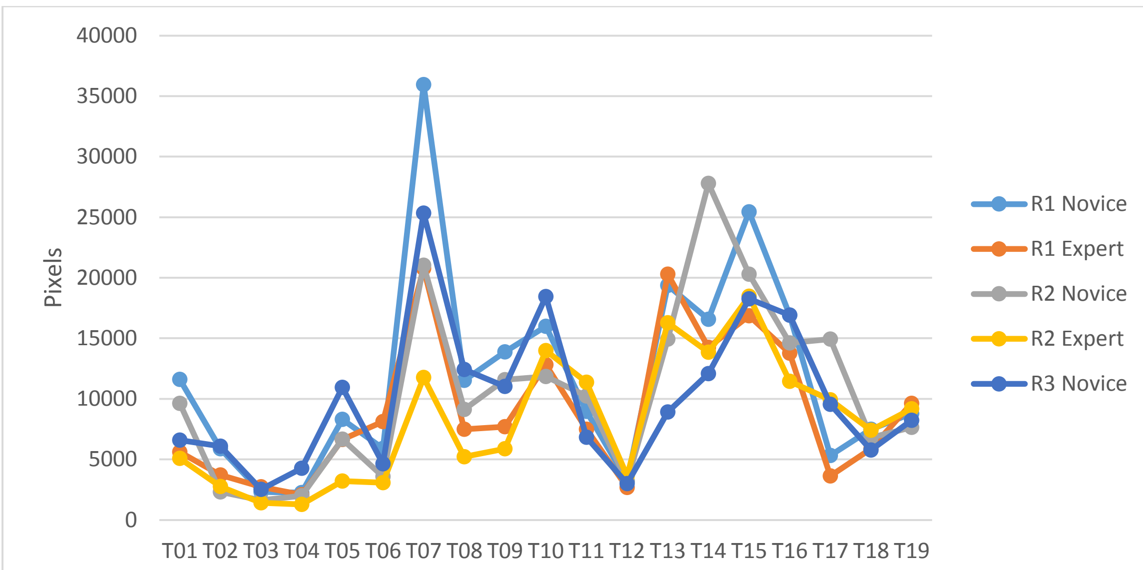

Figure 9 Geometric mean values of mouse movement, length of the navigation path to complete a given task, were compared between two physician groups across three rounds. There was a 14% decrease in novice resident physicians' mouse movements between round 1 and round 2 (R1: 9,247 pixels CI [6,404 pixels, 13,353 pixels], R2: 7,992 pixels CI [5,350 pixels, 11,936 pixels]). There was a 6% increase in novice resident physicians' mouse movements between round 2 and round 3 (R2: 7,992 pixels CI [5,350 pixels, 11,936 pixels], R3: 8,480 pixels CI [6,273, 11,462]). There was an 8% decrease in novice resident physicians' mouse movements between round 1 and round 3 (R1: 9,247 pixels CI [6,404 pixels, 13,353 pixels], R3: 8,480 pixels CI [6,273, 11,462]). There was also a 14% decrease in expert resident physicians' mouse movements between round 1 and round 2 (R1: 7,325 CI [5,237 pixels, 10,247 pixels], R2: 6,329 pixels, CI [4,299 pixels, 9,317 pixels]). There was a 30% increase in expert resident physicians' mouse movements between round 2 and round 3 (R2: 6,329 CI [4,299 pixels, 9,317 pixels], R3: 8,235 pixels CI [5,953 pixels, 11,392 pixels]). There was a 12% increase in expert resident physicians' mouse movements between round 1 and round 3 (R1: 7,325 CI [5,237 pixels, 10,247 pixels], R3: 8,235 pixels CI [5,953 pixels, 11,392 pixels]).

System Usability Scale

In round 1, five out of six expert resident physicians and all ten novice resident physicians completed the SUS. In round 2, all four expert resident physicians and all nine novice resident physicians completed the SUS. In round 3, all first (9), second (8), and third (12) year resident physicians competed the SUS. In round 1, novice resident physicians ranked the system's usability at a mean of 68 (high marginal) and expert resident physicians rated the system's usability at a mean of 70 (acceptable). Two novice resident physicians and one expert resident physician gave a score below 50 (not acceptable). In round 2, novice resident physicians ranked the system's usability at a mean of 69 (high marginal) compared to 68 (high marginal) in round 1. Experts rated the system's usability at a mean of 74 (high marginal) in both rounds. In round 2, one novice physician and two expert resident physicians gave a score of 50 (not acceptable) or below. These results may indicate that expert users who should have achieved a certain level of proficiency may be more confident using the EHR unlike novice users which may be the reason why expert resident physicians gave a higher SUS score than novice resident physicians. In round 3, first year resident physicians ranked the system's usability at a mean of 51 (low marginal) compared to 69 (high marginal) in round 2 and 68 (high marginal) in round 1. Second year resident physicians ranked the system's usability at a mean of 64 (high marginal) and third year resident physicians ranked the system's usability at a mean of 62 (high marginal) compared to 74 (high marginal) in both rounds. This result may indicate that proficiency or length of time using the system does not affect the acceptance of the EHR by novice and expert resident physicians. Debriefing session confirmed the overall usability test experience but did not reveal specific usability issues. After analyzing the recording, however, it was clear that physician encountered some difficulties when completing the tasks.

CHAPTER 5: RESULTS – USABILITY THEMES

Usability Issues Identified by Sub-task analysis

Sub-task analysis was instrumental in identifying multiple usability concerns (Table 4). There were thirty-one common usability issues observed among both novice and expert resident physicians, two unique usability issues identified among novice resident physicians and two unique usability issues identified among expert resident physicians. Table 4 describes usability issue identified, an example of the usability issue found in the EHR, implication on clinical practice or workflow, suggestion for improvement, and severity rating across two rounds.

In round 1, the most common usability issues identified was found by physicians attempting to complete Task 7: Document new medication allergy, Task 13: Include diagnosis, Task 15: Place order for Basic Metabolic Panel (BMP), and Task 16: Change a Medication, Task 17: Add a medication to a favorite list. In round 1, three out of seven expert resident physicians and four out of ten novice resident physicians did not successfully complete Task 7: Document new medication allergy. For example, to complete this task, physicians would have to use a drop down box to change the status from ‘canceled’ to ‘active,’ which is an unanticipated preset due to the EHR test environment. Two novice resident physicians tried to type in the text field labeled ‘Substance’ that was not meant for typing. One novice physician went into the Histories tab first to find Allergies, which is incorrect, then found Allergies below the patients’ name. In round 2, each physician was given a task of making new medication order and was to add the allergy “hives.” With this change in round 2, all novice and expert resident physicians were able to successfully complete Task 7 because the status of the medication allergy was automatically populated to ‘Active’ instead of ‘Canceled’ when adding a medication allergy to an already existing medication. In round 3, seven first year resident physicians were able to successfully complete Task 7, one first year resident physician was not able to include the reaction ‘hives’ to the allergy documentation, and one first year resident physician was not able to successfully complete Task 7. All second year resident physicians were able to complete task 7. Ten third year resident physicians successfully completed Task 7, one first year resident physician was not able to include the reaction ‘hives’ to the allergy documentation, and one first year resident physician was not able to successfully complete Task 7.

When completing Task 13: Include diagnosis, some resident physicians were unclear on how to import a list of diagnoses from the Problem list into the visit note. In round 1, four novice resident physician and one expert resident physicians were unaware that they should highlight all the diagnoses before clicking ‘Include’ to get the entire list of diagnoses into the visit note. In round 2, all novice resident physicians were able to correctly import the diagnoses from the Problem list into the visit note, however, one expert resident physician still had difficulty importing the diagnoses from the Problem list into the visit note. Three novice and four expert resident physicians did not use IMO Search field to shorten steps to add a diagnosis to the note. In round 3, two first year resident physicians and four third year resident physicians were not aware that they should highlight all the diagnoses before clicking ‘Include’ to get the entire list of diagnoses into the visit note. One third year resident physician did not move ‘hypertension’ from the problem list to the current diagnosis list so they re-added ‘hypertension’ as a new problem. Three first year resident physicians, two second year resident physicians, and seven third year resident physicians did not use IMO Search field to shorten steps to add a diagnosis to the note.

When completing Task 15, nine out of ten novice resident physicians and one out of six expert resident physicians in round 1 did not place two orders concurrently. In round 1, one novice resident physician mentioned that there was a way to order them both at the same time but did not know how. In round 2, only one novice resident physician did not place the two BMP orders concurrently. In round 3 four first year resident physicians, three second year resident physicians, and four third year resident physicians did not place the two BMP orders concurrently.

When completing Task 16: Change a Medication, resident physicians had to choose from the right click menu options ‘Renew’, ‘Cancel/DC’, or ‘Cancel/Reorder.’ In round 1, novice resident physicians may have spent extra time on this task because resident physicians were unclear of what option to use among these three options. Right-click of a medication brought up a menu list with a menu item labeled “Modify without resending.” In round 1, six out of ten novice and two out of six expert resident physicians attempted to use this menu option although it was not the correct menu item. In round 2, four out of ten novice and two out of six expert resident physicians attempted to use this menu option although it was not the correct menu item. To change a medication, the recommended menu item to choose was ‘Cancel/Reorder.’ In round 3, physicians were able to complete task 16 by use the option “Modify without resending” by changing the number of tablets the patient needed to take. To complete task 16, three first year resident physicians used the ‘Cancel/DC’ option, two first year resident physicians used the ‘Cancel/Reorder’ options, three first year resident physicians used the ‘Modify without resending,’ and one first year resident physicians used the ‘Complete’ option. Six second year resident physicians used the ‘Cancel/Reorder’ options and two second year resident physicians used the ‘Modify without resending.’ Five third year resident physicians used the ‘Cancel/Reorder’ options, four third year resident physicians used the ‘Modify without resending,’ and three third year resident physicians used the ‘Reconcile’ option.

When completing Task17: Add a medication to a favorite list, resident physicians were asked to add a medication to a list of their frequently used medications. In round 1, three out of seven expert resident physicians and four out of ten novice resident physicians did not successfully complete. One novice and one expert resident physician did not even attempt to add the medication to their favorites. However, in round 2, two out of nine novice resident physicians and one out of five expert resident physicians were not able to complete this task. An expert resident physician mentioned not knowing how to add a medication to their favorites list although this has already been taught in the EHR training program at UMHS. Adding a medication to a favorites list can only be done when the order detail view is open, where medications specifics, such as, dosage, are included. In round 3, five first year resident physicians, three second year resident physicians, and five third year resident physicians were not able to complete task 17. This functionality was not intuitive because this feature was not accessible directly from the medication list, which defeats the purpose and reduces the likelihood of physicians using this feature.

Thematic Analysis of Usability Issues Identified

Five themes emerged during analysis: inconsistencies, user interface issues, structured data issues, ambiguous terminologies, and workarounds. Themes were created by analyzing and combining usability issues to form an overarching theme (1). *Inconsistencies* are being defined in this study as a lack of uniformity among different elements, such as naming conventions, and location of buttons, in the EHR. Six common inconsistencies were identified among both resident physician groups. *User interface issues* are difficulties that arise when the physician interacts with the EHR's screen menus and icons. Eight common and one unique user interface issues were identified. *Ambiguous terminologies* are obscure labelling of items in the EHR that makes the system difficult to understand. Six common and one unique usability issues related to ambiguous terminologies were identified. *Structured data issues* are complications caused by data that resides in a fixed field, such as drop down menus, within the EHR. Six common structured data issues were identified. *Workarounds* are working processes that diverge from intended work methods to bypass issues instead of fixing them (96). Four common and two unique workaround usability issues were identified.

Usability issues found in this study received severity ratings of one (Minor: Potential for lower quality of clinical care due to decreased efficiency, increased frustration, or increased documentation burden or workload burden) and two (Moderate: Potential for workarounds that create patient safety risks).

Table 4 Usability issues identified from sub task analysis, their implications on practice and suggestions. The five themes we identified in our study were: inconsistencies, user interface issues, structured data issues, ambiguous terminologies, and workarounds. Six common usability issues were related to inconsistencies, eight common and one unique usability issues concerning user interface issues, six usability issues in relation to structured data issues, six common and one unique ambiguous terminology usability issues, and four common and two unique usability issues in regards to workarounds.

INCONSISTENCIES				
Usability Issue	**Example of usability issue**	**Implication on clinical practice or workflow**	**Suggestion for improvement**	**Severity Rating**
Inconsistent ordering of command/ action buttons	Tasks 14 – 16 & 18 - The location of buttons “Orders for Signature”, “Sign”, and “Done” varied depending on the window that is being used when signing for orders completed in the CPOE.	Orders may not get completed because physicians ignore the alert warning that “some tasks are not complete. Are you sure you want to leave this chart?”	Interface change: Do card sort /user mental mapping process to see what terms physicians find more natural.	2
Inconsistent labeling of action buttons.	Tasks 7, 9, 11, & 13 - Both physician groups were confused about the command button “Include Selected” vs “Include”.	Physicians may unknowingly omit items and take more time repeating the process of adding wanted items because their first attempt was unsuccessful.	Training: Emphasize how to add a diagnosis during EHR training. Simplify the interface by being consistent with labeling action items.	1
Inconsistent use of double mouse clicks	Task 9: Include Family History - In the Family History tab, there are two unlabeled columns, one for positive and one for negative, located underneath the column labeled ‘mother’.	Physicians may mark an item as positive or negative and not know how to clear it.	Interface change: Allow toggling between positive and negative by double clicking.	1

Absent Action buttons	Task 9: Include Family History - The ‘Include’ button to add Family History to the note is only accessible through the clinic note being created but not when you try to add family history from the main menu to the left.	Takes more clicks to enter Family History if not accessed through the note.	Training: Teach physicians to enter Family History through the note and not the left menu item.	1
Illogical ordering of lists	Task 17: Add a medication to your favorites list - Medication list cannot be sorted alphabetically when imported into a patients visit note.	Non-alphabetized lists frustrate physicians when they cannot figure out how to sort the medication list	Interface change: Import medication list to patient visit note in the order that physicians had them sorted in the CPOE	1
Duplicate diagnoses	Task 13: Include diagnosis - The same diagnosis can be added twice because of different naming conventions for the same diagnosis.	Causes an annoyance to physicians	Interface change: Warn of duplicate diagnoses	1
USER INTERFACE ISSUES				
Long note template list	Task 1: Start a new note - Long list of different templates to choose from when creating a note that is not department specific.	Time consuming and more cognitive load to search through template list.	Training: Teach physicians how to configure template list and create their own personal template list	1
Meaningful title for note not required	Task 12: Save the note - Physicians were not required to change the generic title, provided with the progress note template, to a meaningful (specific) title when saving or when creating the note.	Unhelpful title inhibits physicians to know content of visit later. Generic title reveals no summary of visit detail (i.e. no ‘one-line summary’ of visit viewable from list of documents)	Interface change: Have the generic title highlighted to bring attention to the physician, suggesting to edit the title	1

Unexpected terms in date fields	Task 15: Place order for Basic metabolic panel (BMP) - One expert physician did not create a future order for one month because the terminology used was ‘four weeks’ and the physicians kept searching for ‘one month.’	It is confusing and takes doctors a little longer to complete orders.	Interface change: Add an additional choice that says ‘1 month’	1
Misuse of textboxes.	Task 7: Document new medication allergy - Some ‘read only’ fields appeared as editable text boxes. For example, when adding a medication allergy, a text box is highlighted which makes physicians assume that they should type in the textbox when they cannot.	Highlighting a field that cannot be edited fields brings attention to the field suggesting to the physicians that they should enter information into the field, which confuses the physician and wastes time.	Interface change: Do not add yellow highlight to fields that cannot be edited .	1
Required fields are indistinct	Task 7: Document new medication allergy - The status field was not highlighted to indicate to physicians that the status field needed to be changed for the allergy to be active.	Causes mental model mismatch where physicians think a “Cancelled allergy” should not be on the list.	Interface change: Completely remove cancelled allergy items or, remove data from status field and highlight the field in yellow indicating a requirement to enter a new selection.	1
Lack of keyboard shortcuts	Task 13: Include diagnosis - The keyboard shortcut ctrl + A cannot be used to highlight all rows in a list of diagnosis.	Contradicts physician expectations based on functionalities from other applications. Lack of shortcuts take more time and effort to add multiple diagnoses	Interface change: Add keyboard shortcuts where feasible.	1

Unclear menu options	Task 16: Change a Medication - Unclear option that says 'Change Medication'. To change a medication you either use ‘Renew’, ‘Cancel/DC’, or ‘Cancel/Reorder’.	Physicians make the wrong choices, take longer to complete the task because language is confusing.	Interface change: Test the language in the menus with actual physicians to identify the best terms to use.	1
Hiding functionalities one layer down	Task 17: Add a medication to your favorites list - Physicians cannot add medication to a favorite list from the medication list in a patient’s visit note. Adding a med to favorites can only be done in the order detail view, not in the main medication list view.	Physicians are less likely to build a favorite menu therefore, they cannot take advantage of this functionality.	Interface change: Allow the option to add a medication favorite by right clicking the main medication list.	1
Extra mouse clicks	Task 14 – 16 - To see the changes that were made in Cerner’s CPOE, Power Orders, the “Refresh’ button needs to be clicked for the changes to appear. Note: The “Refresh” button improves system performance by reducing frequent queries to the database.	Physicians may not notice there is new information and act without the new piece of information. Confused and frustrated because they expect the results to automatically update	Interface change: Automatically trigger refresh soon after sending new orders. Training: Physicians need to be trained to remember to click ‘Refresh.’	2
STRUCTURED DATA ISSUES				
Lack of distinction between columns	Task 9: Include Family History - To input family history, the blue or white columns (indicating negative vs. positive finding) for the family member were unlabeled.	Physicians were unsure how to mark a family history item, such as cancer, ‘positive’.	Interface change: Labeling the header would help physicians understand what column to use to make a history item positive.	1
“Indication” field not required	Tasks 16 & 18 - Physicians do not usually input the ‘Indication’ when prescribing medication. Physicians were not required to provide a	Would not affect physicians but would affect the patient reading prescription bottle	Training: Promote filling out certain unrequired fields to make EHR meet information needs of patient.	1

	diagnosis to justify a medication and therefore some physicians did not feel it was important or necessary to enter a reason for prescribing the drug.	with no “reason” information.		
Structured data unutilized	Task 13: Include diagnosis - If physicians use free text, the diagnosis will not be available for them to select when ordering labs.	Creates duplicate work when physicians have to add diagnosis using structured data when they already used free text to enter diagnosis.	Training: Train physicians to add diagnosis using structured data when ordering labs for the patient.	1
Time consuming to complete tasks	Task 13: Include diagnosis - Physicians must navigate multiple screens, go through a number of clicks, and scroll through a long list to find and select a diagnosis.	Time consuming for physicians when inputting diagnosis in patient visit note.	Intelligent Medical Objects (IMO) search is available but appears inactive because the field is gray. Many physicians are unaware of this tool so IMO field color should be changed from gray to black.	1
Unclear import function	Task 13: Include diagnosis - Physicians do not know they should highlight all the diagnoses before clicking ‘Include’ to get the entire list of diagnoses into the visit note.	Takes more time when physicians have to repeat the process of adding wanted items because physicians’ first attempt was unsuccessful.	Interface change: Simplify the interface by being consistent with labeling action items	1
Diagnoses can only be deleted one at a time.	Task 13: Include diagnosis - Multiple diagnoses cannot be deleted altogether.	Takes a longer time for physicians to remove multiple diagnoses	Interface change: Add that functionality to the primary ‘Problem and Diagnosis’ tool.	1

			Training: Use the 'FamMed ViewPoint' or 'IntMed ViewPoint' widget labeled 'Consolidated Problems' to access multi-select functionality	
AMBIGUOUS TERMINOLOGY				
Multiple fields with the same functionality	Tasks 14 & 15 - There is no clear difference between the drop down labeled 'Requested Start Date', the drop down labeled 'Requested Time Frame', and the radio button labeled 'Future Order'	Future labs may not be ordered properly so labs may not be completed at the right time. Patients may have to get the test redone, which brings additional cost to the patient.	Interface change: Remove fields that may be duplicates from the interface, or make them more understandable with additional hints.	2
Unclear terms	Task 13: Include diagnosis - Unclear difference between 'Other Diagnosis' vs 'Other under the Diagnosis' subsections	Physicians lack understanding that "Other" is a free text box and "Other Diagnosis" opens tool for 'Problems and Diagnosis menu item	Interface change: Change name of "OTHER" to "FREE TEXT" or similar term by using open card sort to get physician mental model to understand the physicians' thought process in order to better label items in the EHR	1
Unclear difference between 'All Results' and 'Lab Results'	Task 11: Include last Comprehensive metabolic panel (CMP) - Physicians try to find CMP results from 'All Results' subsection but it is located in the 'Lab Results' subsection.	Terms are misleading to physicians and physicians have to figure out the meaning of both terms.	Training: Teach physicians the difference during EHR training and keyboard shortcuts for lab results, such as, typing "..CMP" to import CMP lab results.	1
Unclear terms.	Task 13: Include diagnosis - There are three different sections labeled	Physicians are unsure of what term to select.	Interface change: Simplify the interface by being	1

	‘Diagnosis’ under the ‘Impression and Plan’ section of the note that physicians clicked on.		consistent with labeling action items.	
Missing symptoms	Task 8: Include Review of Systems - ‘Dry mouth’ and ‘clear nasal discharge’ missing from symptoms list	Physicians have to type in symptoms that are not included in the symptoms list	Interface change: Include common symptoms in the symptoms list	1
Search results do not match physicians’ expectation s.	Task 15: Place order for Basic metabolic panel (BMP) - A search for BMP, blood tests that provides information about patient’s body's metabolism, retrieves multiple versions of same test with different order detail completion.	Takes extra effort for physicians to complete orders.	Interface change: Pare down menu options. Remove unnecessary option or simplify menu choices.	1
Vague wording for alerts	Task 14: Place order for chest x-ray - A novice physician tried to order a chest X-ray but continuously received an error: “Radiology orders should be placed following downtime procedures during 2200 and 0000.”	Physician becomes frustrated and spends time trying to decipher the meaning of the alert and may ignore (alert fatigue).	Interface change: Create more meaningful alerts where the physician can clearly understand the next steps	2
WORK AROUNDS				
Extra steps to complete multiple orders	Task 15: Place order for Basic metabolic panel (BMP) - Novice physicians did not know how to create two orders at the same time. One novice physician mentioned that there was probably a way to order them both but did not know how.	Take more steps to complete multiple orders	Training: Train resident on how to place multiple orders.	1

Unawareness of functions	Task 8: Include Review of Systems - Some physicians were not able to add a comment to a symptom by right clicking the symptom.	Physicians omit descriptive comments, or avoid using the discrete diagnosis tools.	Interface change: Add an affordance to allow physicians to "add comments", although it increases the size of the field and take up more space.	1
Unawareness of functions	Task 13: Include diagnosis - Physicians were not able to move 'hypertension' from the problem list to the current diagnosis list so they re-added 'hypertension' as a new problem.	Takes more time for physicians to search for the diagnosis and add it to the active problems list	Training: Train physicians to use the 'Diagnosis' button Interface change: Enlarge 'Diagnosis' button to say, "add to diagnosis" or add a tooltip to "Diagnosis" button.	1
Entering the date in the wrong field	Task 15: Place order for BMP - One expert physician put the future date in the comments field to place a future lab order instead of using the structured date entry field.	If the date is not entered properly, the labs may be completed at the wrong time.	Training: Educate physicians on best practices for inputting future orders	1
Free text option can be used to bypass structured data entry	Tasks 8, 9, 10, & 13 - Instead of selecting a structured term, some physicians used free text to add diagnosis, family history, review of systems, and physical exam.	Time consuming for physicians to enter information using structured data. Also, information may not be fully captured from using structured data	Interface change: Use clinician terms (IMO, SNOMED) for these diagnosis items	1
Structured data not utilized	Tasks 8 & 10 - Physicians rarely expanded the 'short list symptoms' to access more structured codes for symptoms. They just clicked 'OTHER' and type it in.	Time consuming to expand the symptoms list and search for a specific symptom	Training: Train physicians about macro functions to make data entry easier.	1

Usability Themes Discussion

Inconsistencies

Inconsistencies are a lack of uniformity among different elements, such as naming conventions, and location of buttons, in the EHR (97). Inconsistencies in an EHR may cause critical information, such as, a diagnosis or significant family history, to be discarded instead of being added to the patient's note. As another example, illogical order of the medication list and absent action button, may force physicians with limited time to read through the entire medication list may disrupt physicians' clinical workflow. A study by Walji et al., evaluating the usability of a dentistry EHR interface, also identified several similar issues such as, illogical ordering of terms that led time consuming processes to complete simple tasks (91). Allowing medication lists to be sorted alphabetical or by disease may reduce inefficiency in clinicians' workflow that may improve physicians' behavior and decision-making processes (46, 98).

User Interface Issues

User interface issues are difficulties that arise when the physician interacts with the EHR's screen menus and icons (99). Poor interface design, such as, required fields that are indistinct, creates difficulties for physicians to find certain information, which may lead to unsuccessful clinical information searches that further frustrate busy physicians (100, 101). Poor user interface design of EHRs may also increase the risk of medical errors if important information is not presented in an effective manner (17, 46). In our study, without the option to add a medication to a favorite list from the main medication list, resident physicians may not have utilized this feature and as a result, spent extra time searching for a medication that could have been readily available from the favorites list. Allowing medications to be added to a favorites list from the main medication list would increase the chances of physicians utilizing this useful feature (102). Similarly, the participants in Walji et al's study were unable to modify an entered diagnosis on the "details" page and had to return to previous screens to edit a diagnosis, which may be time consuming to the users.

Ambiguous Terminology

Ambiguous terminologies are obscure labelling of items in the EHR that makes the system difficult to understand. In our study, resident physicians were unclear of the differences among terms, such as, the drop down menu labeled 'Requested Start Date', the drop down menu labeled 'Requested Time Frame', and the radio button labeled 'Future Order', which eventually has the same function. This may have confused resident physicians causing future labs to not be completed in a timely manner. Patients may have to get the test redone, which brings additional cost to the patient. A study by Kjeldskov et al (75) investigated the nature of usability problems experienced by novice and expert users across two rounds of usability evaluations. Nurses who had just completed EHR training were considered novices and the same nurses were evaluated 15 months later and were considered expert. They found 103 usability issues with the most common issues under the theme of complexity of information.

Redundancy in structured data fields, could also impact the quality of documentation by causing errors when documenting a patient's visit (103-108). Removing duplicate fields may further improve the system's usability by preventing physicians from choosing unclear options to choose.

Structured Data Issues

Structured data issues are complications caused by data that resides in a fixed field such as drop down menus, within the EHR (109). In our study, if a data field was not highlighted in yellow, indicating that that the field is required to be filled, resident physicians left the field blank. For another example, because the "Indication" (diagnosis) field is not required when resident physicians were completing tasks in the CPOE, resident physicians did not usually input the 'Indication' when prescribing medication. In other words, resident physicians were not required to provide a diagnosis to justify a medication therefore some resident physicians did not feel it was important or necessary to enter a reason for prescribing the drug. Although the field was not required, it may lead to information gap in the EHR. Callen et al. observed a similar issue that clinicians attempted to save time when using a CPOE system by inserting a period in a required field instead of entering the patient's clinical history. This created an issue where important information was not included in documentation (110). The presence of these tactics to circumvent required fields shows how significant it is for vendors to be innovative when designing data entry structure to meet the needs of the physicians (17, 75, 111).

Workarounds

Workarounds are working processes that diverge from intended work methods to bypass issues instead of fixing them (96). If physicians find completing a task in the EHR too complex because of the system's weakness, they may create workarounds (112). For example, in our study, novice resident physicians took extra steps to complete multiple orders in Task 15: Place order for Basic metabolic panel (BMP) because novice resident physicians did not know how to create two orders at the same time. A study by Cresswell et al., found that lack of customization, led users to create a variety of workarounds to make up for the perceived weakness of the system (113).

Severity ratings

Usability issues found in this study received severity ratings of one (Minor: Potential for lower quality of clinical care due to decreased efficiency, increased frustration, or increased documentation burden or workload burden) and two (Moderate: Potential for workarounds that create patient safety risks). Although the usability issues found were ranked low on the severity scale, these errors may culminate to create critical ones and cause significant errors.

CHAPTER 6: DISCUSSION

Overall, this study was able to identify varying degrees of learnability gaps between expert and novice physician groups that may be impeding the use of EHRs. This study suggests that longer experience levels with EHR may not be equivalent to being an expert, proficient in using EHR. By collecting physicians' interaction with the EHR, these results may be communicated to EHR vendors to assist in improving the user interface for physicians to use effectively. This study may also assist in the design of EHR education and training programs by highlighting the areas (i.e. tasks and related features and functionalities) of difficulty resident physicians are currently facing. Resident physicians in primary care are now offered extensive EHR training by their institutions. However, it is a great challenge finding enough time to train busy physicians. It is an arduous chore when attempting to meet the needs of users and provide hands-on, on-site support (33). There is scarcely any evidence based guidelines for training resident physicians effectively on how to use EHRs for patient care (114). Thus, our study may also serve as a guideline to potentially improve the current EHR training program, which may increase physicians' performance, by improving competency when using the system.

This study was also able to identify usability issues between expert and novice resident physicians that may be impeding the use of EHRs. The study suggested that higher experience levels with EHR is not equivalent to being an expert, proficient in using EHR. Training physicians to use the EHR may decrease difficulty of completing tasks in the EHR. A study by Yui et al, reported that lack of training was one cause for physicians' inexperience with the EHR (116). Another study by Devine et al., examining the effect of an ambulatory CPOE on medication errors and ADEs, found that frequency of errors reduced from 18.2% to 8.2% after training physicians (117). Improving physician training may reduce the amount of workarounds created that may lead to workflow problems. Primary care physicians are now offered exhaustive EHR training by their institutions. However, it is a great challenge finding enough time to train busy physicians. It is an arduous chore attempting to target training specific to the needs of physicians and provide hands-on, on-site support (33). While there is no widely accepted evidence based guidelines for training residents effectively (114), this study may assist in the improving EHR education and training programs by highlighting the areas of difficulty residents are currently facing. These results may also assist EHR vendors in improving the user interface for physicians to use effectively. Improvement in the EHR's usability will enhance user satisfaction and improve proficiency. This may increase physicians' competency when using the system. Future studies should include a larger sample of physicians and broaden the scope to specialty physicians for generalization of results.

Limitations to This Study

This study had several limitations to our methodology. First, this study involves a small sample of physicians in one health care institution where only one EHR system is used and may not be representative of all primary care practice. As such, the study's findings may have limited generalizability to other ambulatory clinic settings due to the selection with different types of EHR applications and physician practice settings. However, the EHR platform employed in this study is one of the top commercial products with significant market share. Second, a limited number of clinical tasks was used in the usability test and may not encompass other tasks completed by physicians in other clinical scenarios. However, these tasks contained realistic inpatient and outpatient tasks that resident physicians would usually complete in a clinical scenario. Third, this study was conducted in a laboratory setting which does not take into account common distractions physicians may experience during a clinical encounter. Nonetheless, lab-based usability tests allow for flexibility in questioning and give room for more in-depth probing. The direct observation in lab usability testing also allows for interaction between participant and facilitator. Although this study contains some methodological limitations, we believe this is a well-controlled study that used rigorous evaluation method with validated usability measures that are widely accepted in HIT evaluation. Also the clear instruction allowed the physician participants to complete the required tasks without excessive cognitive load.

Conclusion

This study found differences in novice and expert physicians' performance, demonstrating that physicians' proficiency did increase with EHR experience. Future directions include identifying usability issues faced by physicians when using the EHR through a more granular task analysis to recognize subtle usability issues that would have otherwise been unnoticed. Also, exploring associations between performance measures and usability issues will also be studied. Training physicians to use the EHR may decrease difficulty of completing tasks in the EHR. Improving physician training may reduce the amount of workarounds created that may lead to workflow problems. These results highlight the areas of difficulty resident physicians with different experience levels are currently facing, which may potentially improve the EHR training program and increase physicians' performance when using an EHR.

CHAPTER 7: APPENDIX

Literature Review Search Strategies

CINAHL search strategy

Search Terms	Search Options	Search Results
S8	S3 AND S6	(348)
S7	S3 AND S4 AND S5 AND S6	(1)
S6	S1 OR S2	(6,102)
S5	(MH "Expert Nurses") OR (MH "Expert Clinicians") OR "expert"	(14,896)
S4	(MH "Novice Nurses") OR (MH "Novice Clinicians") OR "novice"	(2,714)
S3	(MH "Medical Records") OR (MH "Computerized Patient Record") OR (MH "Patient Record Systems") OR "electronic health records"	(24,445)
S2	(MH "User-Computer Interface") OR (MH "Graphical User Interface")	(5,020)
S1	"usability"	

PubMed search strategy

Query	Items found
Search (("Medical Records Systems, Computerized"[Mesh]) AND (((((("Task Performance and Analysis"[MAJR])) OR "User-Computer Interface"[MAJR]) OR usability evaluation) OR usability testing) OR usability)) AND (((((((new[All Fields] AND user[All Fields] OR "new user"[All Fields])) OR beginner*) OR beginner) OR novice)) AND ((((((master) OR experienced) OR trained) OR skill) OR skilled) OR expert))	18
Search (((((((((new[All Fields] AND user[All Fields] OR "new user"[All Fields])) OR beginner*) OR beginner) OR novice)) AND ((((((master)	19

OR experienced) OR trained) OR skill) OR skilled) OR expert))) AND (((usability evaluation) OR usability testing) OR usability)) AND ("medical informatics"[MeSH Terms] OR "medical informatics"[All Fields] OR "health information technology"[All Fields])	
Search ((((((usability testing) OR usability evaluation) OR usability)) AND (("Medical Order Entry Systems"[Mesh]) OR "Medical Records Systems, Computerized"[Mesh]))) NOT "Health Records, Personal"[Mesh]	384
Search (((((((("Task Performance and Analysis"[MAJR])) OR "User-Computer Interface"[MAJR]) OR usability evaluation) OR usability testing) OR usability)) AND (((((((new[All Fields] AND user[All Fields] OR "new user"[All Fields])) OR beginner*) OR beginner) OR novice)) AND ((((((master) OR experienced) OR trained) OR skill) OR skilled) OR expert))) AND ("medical informatics"[MeSH Terms] OR "medical informatics"[All Fields] OR "health information technology"[All Fields])	128
Search ((((("Task Performance and Analysis"[MAJR])) OR "User-Computer Interface"[MAJR])) AND (((((((usability testing) OR usability evaluation) OR usability)) AND (("Medical Order Entry Systems"[Mesh]) OR "Medical Records Systems, Computerized"[Mesh]))) NOT "Health Records, Personal"[Mesh])) AND (((((((new[All Fields] AND user[All Fields] OR "new user"[All Fields])) OR beginner*) OR beginner) OR novice)) AND ((((((master) OR experienced) OR trained) OR skill) OR skilled) OR expert))	4
Search "Task Performance and Analysis"[MAJR]	8435
Search "User-Computer Interface"[MAJR]	13416
Search "Information Systems"[Mesh]	170989
Search usability testing	832
Search "medical informatics"[MeSH Terms] OR "medical informatics"[All Fields] OR "health information technology"[All Fields]	342644
Search health information technology	362548
Search health informatics	352410
Search specialist	77100
Search master	23339
Search experienced	215168
Search experiences	130613
Search trained	87271
Search skill	27452

Search skill*	165308
Search skilled	16884
Search expert	94003
Search new[All Fields] AND user[All Fields] OR "new user"[All Fields]	16002
Search new user	16002
Search beginner*	1377
Search beginner	443
Search novice	4684

SCOPUS Search Strategy

Query	Document Results
((TITLE-ABS-KEY (usability)) OR (TITLE-ABS-KEY (user computer interface))) AND ((TITLE-ABS-KEY ("electronic health record")) OR (TITLE-ABS-KEY ("electronic medical record")) OR (TITLE-ABS-KEY (medical order entry))) AND ((TITLE-ABS-KEY (novice)) OR (TITLE-ABS-KEY (expert)))	120
((TITLE-ABS-KEY (usability)) OR (TITLE-ABS-KEY (user computer interface))) AND ((TITLE-ABS-KEY (electronic health record)) OR (TITLE-ABS-KEY (electronic medical record)) OR (TITLE-ABS-KEY (medical record order entry)) OR (TITLE-ABS-KEY (medical order entry))) AND ((TITLE-ABS-KEY (novice)) OR (TITLE-ABS-KEY (expert)))	142
(TITLE-ABS-KEY (novice)) OR (TITLE-ABS-KEY (expert))	316,239
(TITLE-ABS-KEY (electronic health record)) OR (TITLE-ABS-KEY (electronic medical record)) OR (TITLE-ABS-KEY (medical order entry))	39,552
(TITLE-ABS-KEY (usability)) OR (TITLE-ABS-KEY (user computer interface))	148,495
TITLE-ABS-KEY(novice)	16,952
TITLE-ABS-KEY(expert)	304,302
TITLE-ABS-KEY(medical order entry)	3,777
TITLE-ABS-KEY(electronic medical record)	33,923
TITLE-ABS-KEY(electronic health record)	27,600
TITLE-ABS-KEY(user computer interface)	112,489
TITLE-ABS-KEY(usability)	41,746

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