Finding the Safer Way: Novel Interaction Design Approaches to Health IT Safety: Final Report

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A. ABSTRACT

Purpose:

This research aims to understand interaction design in electronic health records and whether a novel 'composable' approach could help solve some of the existing problems of display fragmentation, cognitive load, interruptions and their effects on clinician performance, information needs, use patterns, and clinical reasoning/workflow in locating, understanding and using information in EHRs in typical tasks.

Scope:

We conducted laboratory and simulation experiments to determine the effects of different EHR design approaches, on clinical reasoning, efficiency, fit to task, display fragmentation, and other parameters.

Methods:

Mixed methods included think aloud protocols, cognitive walkthroughs, simulation studies in a simulated emergency department setting designed to replicate effect of interruptions, eye tracking of users using conventional and composable systems, and related interviewing and thematic analysis. This design includes a crossover study of users using a conventional and composable systems, observation and interview of users of conventional systems, analysis and mapping of navigation and user interfaces in conventional EHRs, and other techniques.

Results:

The results confirm advantages for the composable approach in addressing display fragmentation and related issues. Several design patterns for which alternative interaction designs may be more efficient were identified.

Sharing and deliberate omissions or errors included in test cases did not result in increased diagnostic errors. Users of conventional systems identified navigation design, flowsheets, the need for repeated clicks, scrolling, redundant navigation or poor ability to find information as major issues with conventional systems. Interruptions in simulation of ED work did result in back and forth navigation in conventional systems.

Keywords:

Composable approach, Electronic health records, EHRs, EMRs, Human-computer interaction, clinical reasoning, clinical cognition, cognitive load, clinical workflow.

B. PURPOSE

The project detailed in this report titled, *Finding the Safer Way: Novel Interaction Design Approaches to Health IT Safety*, had the following aims:

1. **To understand the effect of the display fragmentation problem on cognitive load and its effect on clinician performance in locating, understanding and using information in EHRs in typical tasks** using a novel tool real-time in laboratory studies of realistic tasks.

2. **To understand clinician information needs and use patterns for clinician users in a variety of specialties and roles, and to understand information transfer among these clinicians.** We will assess the variability, criticality, combinations, and dynamism of information needs for different specialties, by a) using real-time tool as they assess a case b) analyze their own designs for common tasks they state are important in their specialty c) analyzing how they select and transmit information to colleagues.

3. **To understand the effect of composable and conventional approaches on clinical reasoning and errors. This includes high-stress scenarios with multiple patients and nonlinear workflow**.

To accomplish these aims, four studies were conducted with the following objectives, respectively:

1. Examine the effect of fragmented displays and a composable display on cognitive load and task performance;
2. Assess user cognitive load and information needs when using conventional, fragmented displays;
3. Examine how use of a composable system affects communication and information transfer between users and affects error detection and performance; and
4. Assess the effect of the composable system on clinical reasoning and performance, specifically in high-stress, interruption-prone scenarios.

C. SCOPE

C.1 Background and Context

Healthcare information technology (HIT) and electronic health records (EHRs) have the ability to improve care, reduce costs, and create a ‘learning healthcare system’ (1-3). However, optimal interaction design of such software has proven difficult, with potential for HIT itself to introduce safety concerns (4, 5).

The Institute of Medicine (now the National Academy of Medicine) 2011 report (4) identifies several concerns related to EHR interaction design, specifically the use of *fragmented displays*, in which information location is fixed and users must navigate through menus and screens to access the information. Computers compel us to review large amounts of information via a limited screen space thus resulting in a phenomenon known as the *Keyhole effect*. Users cannot see all needed information on the same screen (like only seeing part of a large room through a small keyhole) (6). As a result, the display fragmentation resulting from the relevant information being located on different screens, can lead to increased *cognitive load* – or the use of limited working memory resources – as users have to frequently switch screens, identify useful information, and then hold that information in memory as they navigate to another screen (4). By the time users navigate to and begin processing the information on the second screen, they may forget the information on the first screen, leading to more navigation and screen switching actions (see Figure 1) (7).

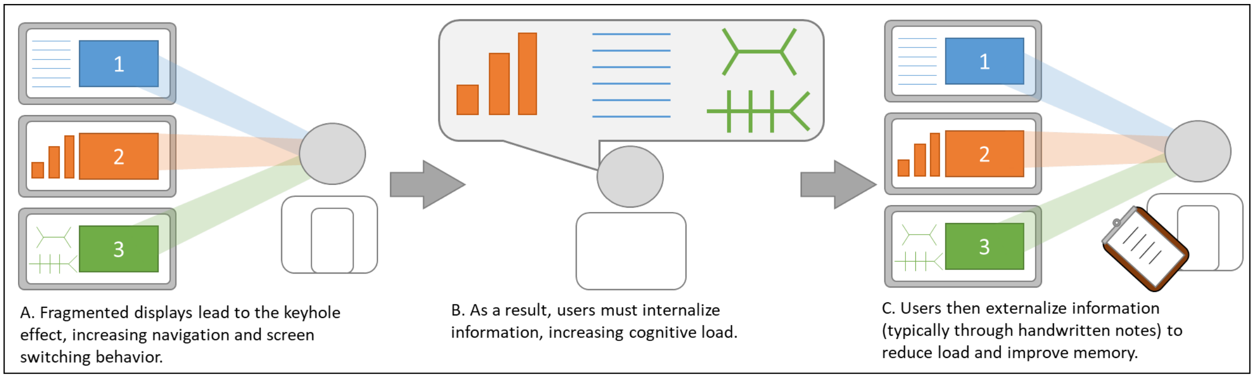


Figure 1. The problem of fragmented displays, the keyhole effect, and increased cognitive load in conventional systems.

The burden on clinician time and cognitive load is not insignificant and can impact patient care and safety. One study has shown that conventional EHRs can require six times the number of clicks and screen transitions for users to obtain complete information needed for a task (8) than if the information were all located on the same screen(9). Additionally, fragmented displays mean that important data patterns needed to make clinical decisions may not be salient for the clinician to notice and act on, *or* clinicians spend more time and energy processing information. Clinicians may also have less time with patients and fewer working memory resources available for diagnostic decision-making and treatment, increasing the possibility of error. Researchers have shown that fragmented displays can be a source of clinical error (10, 11).

Another key contextual factor is that clinicians often work in busy settings (e.g., a crowded emergency department), where they can be easily interrupted by another clinician or for a host of other reasons, or needing to switch between multiple patient charts. Interruptions can cause clinicians to 'lose their place' in a task or forget which information they were reviewing, leading the physician to overlook key information, skip a key diagnostic step, or miss/introduce error. Collins et al. found that during a two-hour computerized physician order entry (CPOE) session in a medical intensive care unit (MICU), interruptions occurred on an average of every five minutes followed by two errors (12).

These challenges highlight a greater contextual problem known as poor *'fit-to-task'*. Poor fit-to-task occurs when the software or technology does not meet the needs of the task (13-15). This problem can result from a mismatch between programmer assumptions about the work environment and the actual task and/or work environment, often resulting from a mismatch between developer and clinician backgrounds. Improving fit-to-task can potentially reduce cognitive load, minimize error, and provide cognitive support in cases of interruptions.

<u>The MedWISER System and Distributed Cognition Theory</u>

To address the problems involving the keyhole effect, cognitive load, interruptions, and fit-to-task, an experimental system titled MedWISER (Medical Widget-based Information Sharing Environment) was developed. This application utilizes a distinctive interaction style in which the user can assemble desired information elements (such as lab panels, notes, problem lists, x-ray reports, RSS feeds, orders, data plots, medications) together on the same screen or use preset summaries created by other clinicians.

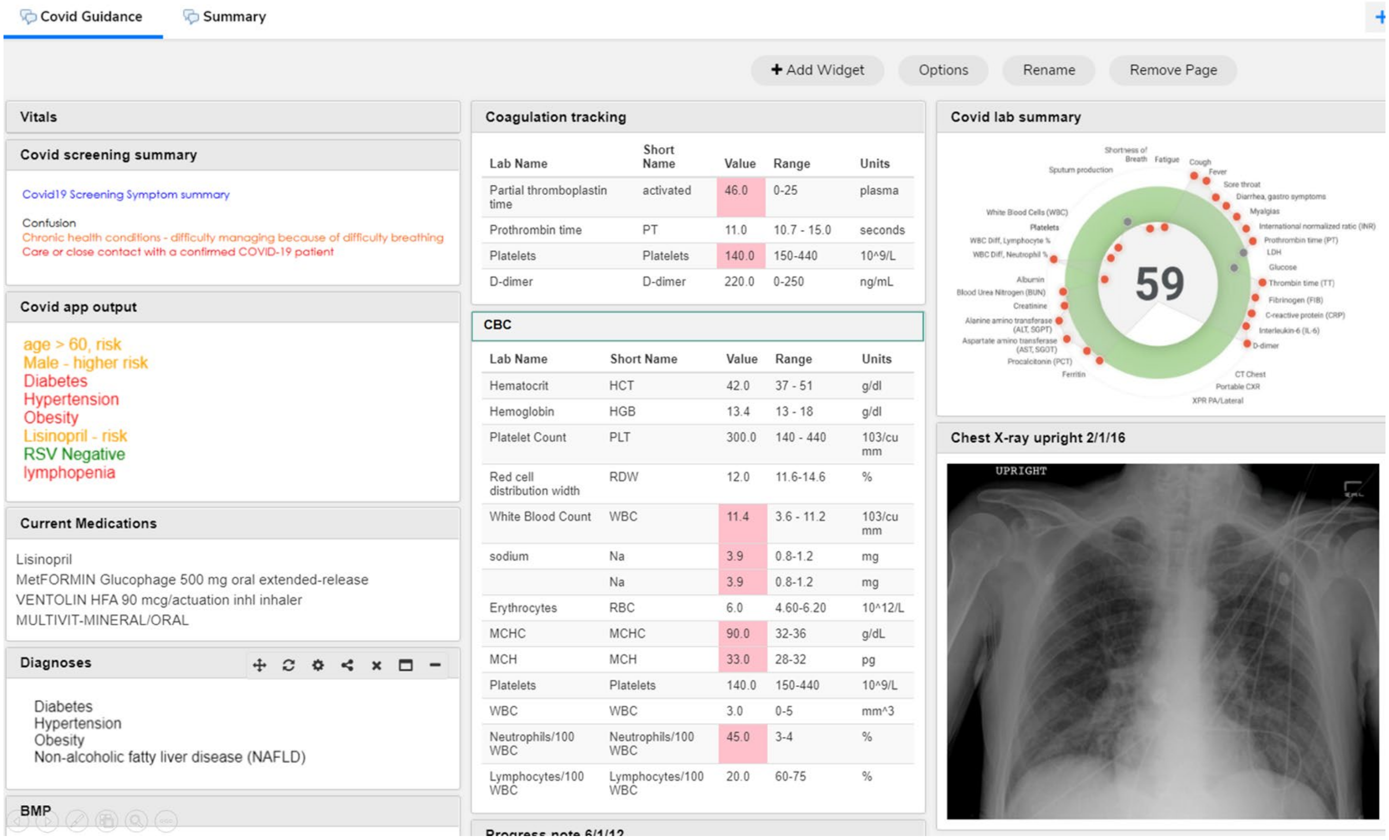


Figure 2. Screenshot of MedWISER.

MedWISER's design is grounded in *distributed cognition theory (DCT).* DCT is comprised of two relevant concepts:

1. First, cognition should not be thought of as isolated to the individual. In complex work systems such as healthcare, it is something that occurs across entire system of humans, paper and other tools, computers, etc. (16). Work takes place by coordination across all these systems, usually by using representations which must match at each stage.
2. As a consequence, the division of information representation, either internal (e.g., held in the user's mind) or external (e.g., on paper or on screen), is closely related to usability. As information externalization increases, usability increases (17, 18).Users can externalize information on screen or by writing information down on paper, etc. A familiar example is jotting down a phone number to remember it briefly to make the call.

This second concept directly relates to the problems of cognitive load and the keyhole effect. The more users internalize information and switch screens, the greater the cognitive load as users must retain things in working memory from one screen to the next. It is well established that cognitive resources (perception, memory, and attention) are limited (19-21). Therefore, cognitive load imposed by navigating HIT systems leaves fewer cognitive sources for users to complete central tasks (such as diagnostic reasoning). If users have a means of externalizing information, cognitive load should decrease, improving usability and user experience. MedWISER attempts to address this problem by allowing users to compose their own EHR screens with information on a single screen (externalization) that would otherwise be found on separate screens and require users to internalize this fragmented collection of data (see Figure 3).

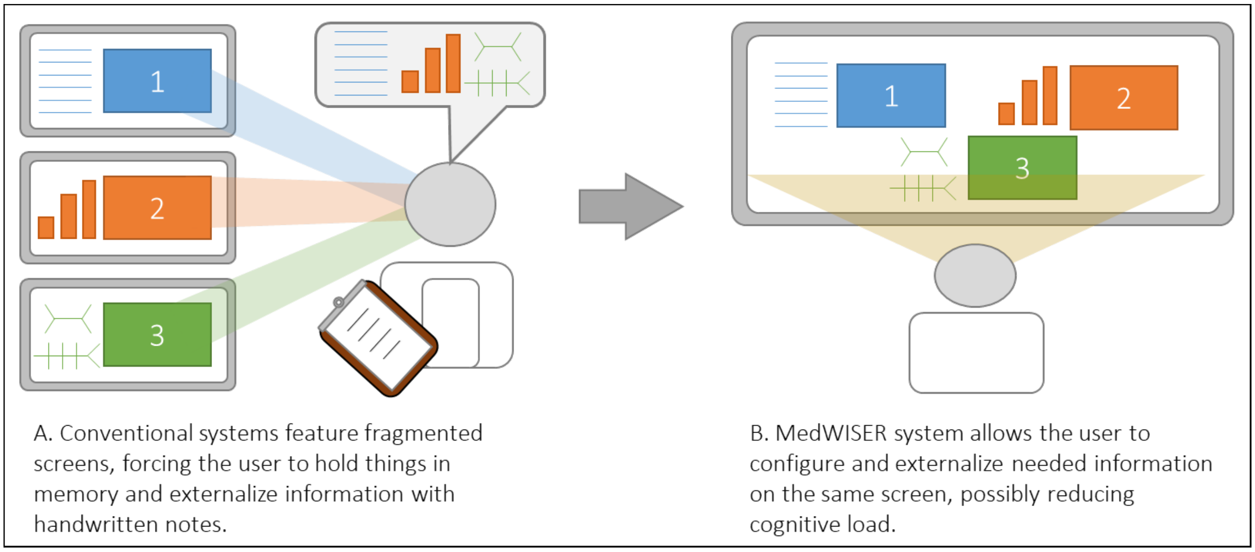


Figure 3. The MedWISER Solution. The user can select which items to place together visibly on the screen. This allows the user to externalize the information and review it directly side-by-side, which can decrease cognitive load, and possibly increase diagnostic reasoning.

The second concept directly relates to our problem of poor fit-to-task. The fragmented nature of EHRs can exacerbate problems related to two contextual factors associated with the healthcare setting and clinician workflow.

The first factor is that clinicians use EHRs to communicate patient information to one another. MedWISER attempts to improve display sharing and communication by allowing physicians to develop a *common ground* display for clinical communication. Once a patient display is created, it can be shared with other users who do not need to locate the information themselves, leading to time savings (22, 23). This idea is supported in research as logfile analyses of clinician's system use predict a 2-7-fold time savings if all members of a care team can share the same interface (3).

The second factor is that the nature of healthcare workflow naturally leaves clinicians vulnerable to interruptions. Interruptions can take many forms, such as emergency patients arriving in a busy emergency room, or the simple need to multitask (e.g., answering questions, approving orders, reviewing charts, taking notes). Interruptions can lead to physicians missing errors or introducing errors into patient records. One way that MedWISER attempts to mitigate the effect of interruptions is again through the patient-specific display, in which the user has aggregated the currently relevant information. Whereas in a conventional system such interruption might require re-navigating across many screens, in the aggregated display the user can simply return to where they left off, with all the prior work in place. This display could also serve to re-orient the user's cognitive processes.

Carefully constructed displays can have an added *checklist effect* (24) if clinicians develop them to be complete collections of relevant elements, perhaps using templates or conventions (based on specific contexts) that all users are familiar with. Senathirajah et al. note that the mere presence of familiar displays can facilitate recall and complete information review when examining an EHR (24).

As noted, four studies were to investigate fragmentation and fit-to-task with the following objectives:

1. Examine the effect of fragmented displays and a composable display on cognitive load and task performance;
2. Assess user cognitive load and information needs when using conventional, fragmented displays;

3. Examine how use of a composable system affects communication and information transfer between users and affects error detection and performance; and

4. Assess the effect of the composable system on clinical reasoning and performance, specifically in high-stress, interruption-prone scenarios.

C.2 Settings

Studies one and two were conducted at academic health systems. Study three was primarily conducted online with subjects from academic health systems. Study four took place at an emergency simulation lab, located at a teaching hospital in New York City.

C.3 Participants

We present the participants by study, as each study had different participant inclusion and exclusion criteria and different number of participants.

C.3.1 Study One: Cognitive Load, Screen Switching, and Working Memory

Primary inclusion criterion for subjects was that subjects needed to be clinicians with prescribing privileges. i.e., medical residents, physician attendings, physician assistants (PA), and certified nurse practitioners (NPs). Subjects were recruited from an academic healthcare system.

C.3.2 Study Two: Assess Information Needs and Task Performance with Conventional Systems

Six (6) clinicians (nurses from a neurology floor) were recruited to participate in semi-structured interviews and a task completion study. Participants were recruited from inpatient settings at a large academic healthcare system.

C.3.3 Study Three: Assessing Composable System Fit to Task

A total of 12 clinicians were recruited to participate in online studies. Clinicians were recruited from large academic medical centers.

C.3.4 Study Four: Testing Clinical Reasoning with Composable and Conventional EHR Approaches

Eight (8) subjects were recruited for this study. All subjects were emergency department residents or other specialties. No PAs or NPs were recruited for the study. All subjects were recruited from the teaching hospital where the simulation lab used for the study was located. Participants provided oral consent

D. METHODS

We present the methods by study.

D.1 Study One: Cognitive Load, Screen Switching, and Working Memory

The objective of the first study was to examine how cognitive load increases or decreases between using fragmented displays (in a conventional EHR) or the composable approach (MedWISER system).

D.1.1 Study Design

A cross-over study design was used. Subjects appraised four realistic and complex patient cases. two with the conventional EHR and two with MedWISER. They first completed a MedWISER training exercise which has been used in the past; findings indicated that subjects were able to learn the basic functions of the system within 20 minutes. After completing the tasks, subjects were given a post-task survey on usability with some open-ended questions.

D.1.2 Data Collection, Analysis, and Measures

The primary method of data collection was screen recording combined with a think aloud protocol (25). As subjects are asked to appraise the patient cases using the conventional EHR and experimental EHR interface, their activity with the interface was recorded using video analytic software (Morae ® from Techsmith, Okemos Michigan). The subjects were also asked to verbalize their thinking (e.g., their thoughts while reasoning, and at the end to summarize their assessment, diagnosis, and plan for the mock patient) as they were using the system and their speech was recorded. These types of think aloud protocols are a standard method used to elicit users' thoughts, reflecting their conscious cognitive activity while interacting with the system (26). Key measures, their definitions, and collection and analysis methods for this study are described in Table 1.

Table 1. Study one measures, data collection methods, and analysis methods.

Measure	Definition	Collection and Analysis
Time spent on task	Total time user spent completing the task, and time on subtasks.	Screen capture; counted in seconds.
Clickstream	Sequence of screen elements the user clicked on.	Screen capture
Number of screen transitions	How many times the user switched from one screen to another.	Screen capture; raw count.
Diagnostic performance	How well the clinicians assessed the patient case.	Think aloud; compared to expert-derived standard.
Time to find information; gaze trace.	How long it took for users to view/locate certain pieces of information; screen focus coordinates.	Eye tracking; counted in seconds.
Completeness of information viewing	The number of elements viewed by the user.	Eye tracking; raw count.

D.2 Study Two: Assess Information Needs and Task Performance with Conventional Systems

The objective of the second study was to elucidate the information needs of clinicians when using EHR systems. To do this study, users completed five tasks and were interviewed about their information needs.

D.2.1 Study Design

Subjects completed tasks using a conventional EHR system with real patient cases and participated in interviews. First, subjects completed five patient assessment tasks (Review Orders, Review Results, Review Documents, Review Flowsheets, Review Clinical Summary, Final Thoughts) using the conventional system with real patient records. Then they were presented with the MedWISER composable system and given basic information about the approach. Finally, they were asked stimulus questions to (1) identify the most urgent problems with current EHR usability/data; (2) state their opinions about possible solutions; and (3) identify which data elements and layout should be on screen for important/difficult conditions or contexts of use. Additionally, we asked them to assess whether the composable system might be useful in addressing the urgent problems with current EHR usability.

D.2.2 Data Collection, Analysis, and Measures

As subjects completed tasks, their actions on screen were captured, and eye tracking and pupillary dilation, a physiologic measure of cognitive load, was recorded and collected as well. Time spent completing each task was derived from recordings. Interviews were recorded and transcribed. Screen capture and eye movements were analyzed to examine time on task and gaze traces (which elements of the screen are subjects focusing on, in what sequence, and for how long). The transcriptions were analyzed using high-level thematic analysis techniques. Table two identifies qualitative and quantitative measures for phase one and phase two of this study.

Table 2. Study two measures, data collection methods, and analysis methods.

Measure	Definition	Collection and Analysis
Common themes	Major concepts and themes emerging from think-aloud protocols	Think aloud; thematic analysis.
Usefulness	User rating (1-5) of usefulness of the system	Semi-structured interview.
Pupillary dilation	Dilation of pupil in response to cognitive load	Eye tracking.
Time spent on task	Total time user spent completing the task, and time on subtasks.	Screen capture; counted in seconds.
Gaze trace	Which areas of the screen are subjects focused on.	Screen capture; calculated by software.

Measure	Definition	Collection and Analysis
Gaze time	How long are subjects focusing on certain areas of the screen for particular subtasks.	Screen capture; calculated by software.

D.3 Study Three: Assessing Composable System Information sharing.

To assess how MedWISER affects user information sharing, online studies were conducted to understand how users may change the composable interface as they share displays previously composed by another person and interact with it one after another.

D.3.1 <u>Study Design</u>

An online study was conducted with a cascade study design. Online studies ensure greater subject recruitment and enrollment. The study was conducted using Microsoft Teams® which allows the investigators to capture recorded video of the users' screen actions, as well as speech.

This study consisted of 12 subjects completing four case review tasks using the MedWISER system; with some displays precomposed as if they had been shared from a colleague. The tasks simulated a clinician reviewing a patient's EHR chart to assess, diagnose, and develop a treatment plan for the patient. This process is a common task clinicians conduct using an EHR. A criticism of the composable approach has been that giving clinicians the ability to configure their interfaces risks their omitting important information, affecting the decisions of subsequent clinicians sharing the interface, if they do not detect the omission or error. We tested whether this concern was true or not, by simulating transmission of the interface between clinicians.

In order to assess clinician ability to detect errors or missing information, deliberate instances of these omissions/errors were introduced into the pre-composed interfaces.

Next, these precomposed interfaces were given to different clinician subjects, with instructions to complete the diagnostic task with each of the four cases, modifying the pre-composed system as they see fit. If they correct any omissions or errors, this correction was noted. These transfers and the changes to the interface between subjects provide insight into key aspects of challenges, such as degree of any distortion of user interface (UI) information, efficient information selection and communication (reduced time spent navigating the system) and the ability of the clinicians to identify possible errors or omissions.

D.3.2 <u>Data Collection, Analysis, and Measures</u>

Overlaps in transmitted information between subject transfers were captured via screen recording and then calculated using Mamykina's SMMi measure, which has been used for similar measurement of handoff effectiveness (27, 28). The use of multiple subjects per transition allows effects of individual variability in clinician information use and common patterns to be discerned.

Table 3. Study three measures, data collection methods, and analysis methods.

Measure	Definition	Collection and Analysis
Error detection	Proportion of errors user was able to identify.	Screen recording
Omission detection	Proportion of omissions user was able to identify.	Screen recording
Changes in UI as a result of error/omission detection	Number of times the user changed the interface to address an error or omission.	Screen recording
SMMi measure	Proportion of overlap in data elements used by 2 users	See Mamykina's SMMi
Time spent on task	Total time user spent completing the task, and time on subtasks.	Screen capture; counted in seconds.
Diagnostic accuracy	Essential Diagnostic features mentioned	Comparison with expert-derived standard features

D.4 Study Four: Testing Clinical Reasoning with Composable and Conventional EHR Approaches

In order to evaluate clinical reasoning, error-rate, near-miss rate, time taken, and other parameters, specifically within the context of a busy clinical setting, a cross over study was conducted with clinicians.

D.4.1 Study Design

A crossover study design was used in which subjects were asked to complete assessments, diagnoses, and treatment plans for realistic (dummy or deidentified) patient cases. The study was designed to simulate a busy emergency room setting with frequent interruptions. Actors (trained standardized patients) were used with subject participants to role-play a simulated emergency room scenario. Subjects, divided into two groups, would have used either a conventional EHR or MedWISER during the scenario to assess, diagnose, and plan treatment for the patients in the scenarios.

In the scenario, each subject started out assessing one patient. Then, a second patient 'arrived' with urgent needs who also needed to be assessed. This design simulated a high stress situation with frequent interruptions. The design naturally forced the subjects to switch between patient records – an action that could lead to increased cognitive load and possible error creation and/or missing information. From this design, we were able to obtain information to deepen our understanding of how clinicians used information in context and how this was affected using conventional or composable systems, including the cognitive and usability effects of multiple patients being treated simultaneously, with realistic interruptions.

D.4.2 Data Collection, Analysis, and Measures

Primary data collection measures included diagnostic accuracy, information completeness, error rate, element overlap (SMMi), time on task, and number of screen transitions and mouse movements. These measures were primarily collected via screen recording and observation and analyzed via count.

D.5 Limitations

Limitations of these studies included the smaller numbers (which are however typical of some types of usability study), technical glitches which required us to repeat some portions, as described earlier, the randomization which in one case resulted in unbalanced assignments (which were remedied later by a different assignment protocol), and in some cases apparent inadequate training in MedWISER. The fact that users are naturally more proficient in the conventional systems they may have used for years could also be a distorting factor. Individual unusual subject behavior could on occasion result in not testing the intended functions (for example, a subject in the interruption study not switching between patients the way all the other subjects did).

E. RESULTS

E.1 Principal Findings

E.1.1 **Study One: Cognitive Load, Screen Switching, and Working Memory**

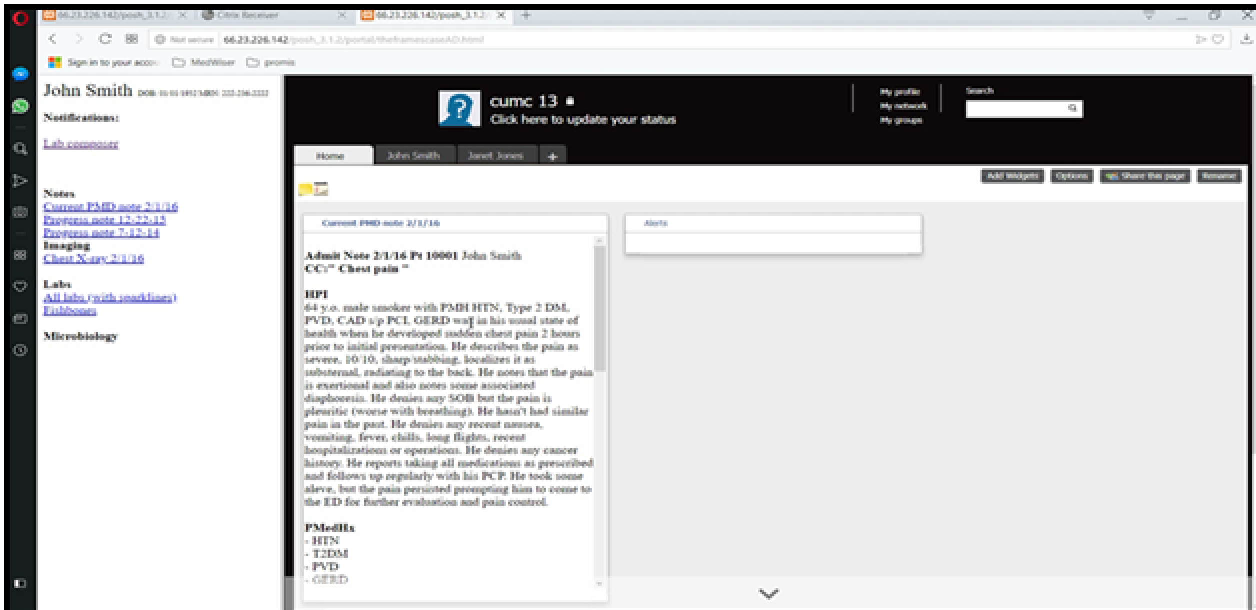
Measure	Definition	Collection and Analysis
Time spent on task	Total time user spent completing the task, and time on subtasks.	Screen capture; counted in seconds.
Clickstream	Sequence of screen elements the user clicked on.	Screen capture
Number of screen transitions	How many times the user switched from one screen to another.	Screen capture; raw count.
Diagnostic performance	How well the clinicians assessed the patient case.	Think aloud; compared to expert-derived standard.
Time to find information; gaze trace.	How long it took for users to view/locate certain pieces of information; screen focus coordinates.	Eye tracking; counted in seconds.
Completeness of information viewing	The number of elements viewed by the user.	Eye tracking; raw count.

This study was carried out with 22 subjects, but technical glitches and concerns about tightening the study design led us to stop it at this point in order to do preliminary data analysis. On analyzing the video recordings, we found that some of the ratings were missing (due to the research assistant's omitting to ask the questions). Subjects were not given adequate training on MedWISER. In addition, the version of Allscripts was different from the one used by residents and did not have the complete function set. This study was adjusted to prevent technical glitches, and new subjects recruited. The following table represents data across the four cases. Different numbers of subjects completed each case because of the randomization scheme used in the study design and the premature halting of the study. Fourteen subjects completed all four and 12 completed just two out of the four. The cases differed in their levels of complexity. There were no observed differences in diagnostic reasoning. Case 2 and 3 offered the clearest comparisons. In case 2, the MedWISER users used more time to complete the case and also employed a greater number of clicks and scrolling behavior. Case 3 shows the opposite pattern with MedWISER users requiring less time and fewer clicks. In general, these subjects did not employ the full capabilities of MedWISER or any of the more advanced strategies employed by clinicians in other studies. Anecdotal observations of the most capable users indicated that they used the placement side by side of documents or other data to view relevant elements together to support their reasoning and needed less time to complete the case, fewer screen transitions and fewer total clicks, though they also employed more scrolling given the limited screen size of the laptop used in the study.

		Total Clicks	Left Mouse	Scroll	Mean Time	N
Case 1	Mean	357.50	71.30	284.70	7:40	10
MedWISER	STDEV	192.13	32.28	182.12	2:50	
Case 1	Mean	259.00	116.00	137.50	6:07	2
Allscripts	STDEV	123.04	117.38	3.54	1:55	
Case 2	Mean	377.14	70.86	304.71	6:40	7
MedWISER	STDEV	201.23	30.43	194.25	2:41	
Case 2	Mean	308.60	67.60	234.40	5:29	5
Allscripts	STDEV	100.20	35.12	106.95	2:14	
Case 3	Mean	196.33	49.17	151.33	5:55	6
MedWISER	STDEV	181.82	33.67	160.94	1:58	
Case 3	Mean	360.75	75.88	278.13	7:25	8
Allscripts	STDEV	188.27	37.96	157.68	5:08	
Case 4	Mean	107.67	58.67	46.00	5:19	3
MedWISER	STDEV	64.30	5.51	56.45	0:39	
Case 4	Mean	241.73	82.73	142.18	6.44	11
Allscripts	STDEV	92.73	38.09	46.53	3:41	

We developed a methodology in which we employed the video capture, click count and verbalizations (i.e., think-aloud protocol) to characterize the sequential process of developing a patient problem representation. This enabled us to better understand the diagnostic and therapeutic reasoning processes and seeds ideas for improving the interactive capabilities of MedWISER. It also provides objectives for training users in how to use the system more productively.

The figure below illustrates a user who begins the process of examining the admission note. Admission note information leads her to gather and process other important patient information. This screen is the first of nine with each one corresponding to a new arrangement of documents or the inclusion of a new document or image (i.e., x-ray or ultrasound). We could observe clinical reasoning strategies including diagnostic hypotheses which were evaluated against incoming information, needs for additional information, proposed further investigation and therapeutic planning over the course of the session. That was among the most illuminating aspects of this study.



OK so he was presenting for chest pain, 64 year old smoker hypertension diabetes peripheral vascular disease coronary artery disease, stress with PCI in the past.

Sounds like he's a lot of vascular comorbidities. Yikes. GERD, chest pain two hours before presentation. Again this is in the past there. Right.

OK. Went to the ED.

Already on aspirin at home, Simvastatin, Metoprolol, Lisinopril for his heart disease, Metformin and Glyburide for his diabetes, smoker... that time he was quite tachycardic and hypertensive and a little bit hypoxic as well. seem to be in some distress.

[00:29:48] Nothing too revealing on physical exam.

E.1.2 **Study Two: Assess Information Needs and Task Performance with Conventional Systems**

Measure	Definition	Collection and Analysis
Common themes	Major concepts and themes emerging from think-aloud protocols	Think aloud; thematic analysis.
Usefulness	User rating (1-5) of usefulness of the system	Semi-structured interview.
Pupillary dilation	Dilation of pupil in response to cognitive load	Eye tracking.
Time spent on task	Total time user spent completing the task, and time on subtasks.	Screen capture; counted in seconds.
Gaze trace	Which areas of the screen are subjects focused on.	Screen capture; calculated by software.
Gaze time	How long are subjects focusing on certain areas of the screen for particular subtasks.	Screen capture; calculated by software.

For the conventional system, some of the interaction design patterns which are particularly problematic included:

Presenting the clinician with a long list of links to notes (pdfs or other formats) which must be individually clicked on, expanded, scrolled to section desired, and repeated for all notes. This method of data presentation is time-consuming (up to 1.5 hours / patient, or ½ hour/patient in critical care). This information review burden may be a threat to safety as time constraints mean not all data is viewed which should be viewed. Informal interviewing of clinicians confirms their concerns in this aspect of UI. We are working on a suggested alternate interaction pattern which would automate note access and abstract relevant sections for presentation in a document which could be quickly scanned, with drill-down to original sections as needed.
Remedies:

1) Preliminary text extraction using automation techniques such as may already be available (e.g Hyland 'Brainware') can extract salient sections based on headings
2) Current Robotic Process Automation (RPA) techniques can step through the EHR navigation software the way a human would do, automating the navigation and extraction, albeit in a non-native manner. Text extraction can then be scanned for relevant sections. Experimental use of RPA is in progress.
3) Design pattern: the UI can present the user with a heading list; the user checks off which sections are of interest (e.g., assessment and plan, at the bottom of the document), and the software fetches those sections; a demo version is in progress for sections, aggregating them in a single document with appropriate dates/times and headings.
4) Color highlighting and list filtering of salient phrases instituted to facilitate rapid review

UI for flowsheets, which presents large sheets with the user required to scroll in both dimensions to see and enter data. This design is quite cumbersome, disorienting, and does not permit appropriate overviews.

Alternate design pattern: make use of mobile-like techniques of edge overview (as with google maps) permitting input for specific ranges of cells and then movement to the next set, but always with the ability to see the active cells in overall context.

Long dropdown lists for item selection – allow for mis-selection and impose cognitive load; both safety issues.

Alternate design patterns: radial selection menus, automated highlighting, Tall man lettering, color highlighting of drug names with interactions with other prescribed drugs, and use of symbols or icons to distinguish drugs or classes, would allow avoidance of conflicts without the usual interruptive alerting systems, Alternating back and forth navigation between note and labs, or other sections. MedWISER facilitates juxtaposition, so set patterns placing these together on the screen can be set up ad hoc. The Sunburst interactive display resulting from the method development of study 5 can be used as an interaction tool aiding item selection and juxtaposition. Automation of common patterns is possible.

Fragmentation of conditions, indications, medications, supporting data. Particularly for patients with complex histories or comorbidities, display fragmentation separates data which should be associated and visible, such as indications why a drug was prescribed, antagonistic effects of medications prescribed by different providers to the same patient, lack of comprehensive overview and detail allowing rapid grasp of the entire patient condition, and interruptive navigation being required to see all data. Specialized visualizations allowing juxtaposition and overviews are being developed.

E.1.3 **Study Three: Assessing Composable System Transmission of data via UI sharing between users, and error/omission detection.**

Measure	Definition	Collection and Analysis
Error detection	Proportion of errors user was able to identify.	Screen recording
Omission detection	Proportion of omissions user was able to identify.	Screen recording
Changes in UI as a result of error/omission detection	Number of times the user changed the interface to address an error or omission.	Screen recording
SMMi measure	Proportion of overlap in data elements used by 2 users	See Mamykina's SMMi
Time spent on task	Total time user spent completing the task, and time on subtasks.	Screen capture; counted in seconds.
Diagnostic accuracy	Essential Diagnostic features mentioned	Comparison with expert-derived standard features

Eleven subjects were run in this experiment, but due to Covid19 it was temporarily discontinued due to university Covid regulations and the finding that users did not necessarily perceive omissions but nevertheless gave accurate diagnoses. Researchers also perceived that 'saturation' of finding usability issues had already been reached, so questioned whether additional subjects were necessary;. we elected not to continue with this design. The cases are being evaluated and recordings analyzed in order to determine further steps.

A majority of subjects using the composed interface mentioned juxtaposition of all important elements on one screen as an important cognitively supportive feature, stating that otherwise (in the conventional system) they had to interrupt clinical reasoning processes in order to consider how to get other pieces of information (which might involve several clicks and screens). Other perceptions stated in post-exercise debriefing and thinkaloud include: a possible improvement in permitting the user to make items smaller rather than collapsed (retaining all information on one screen but minimizing individual elements in a way that information is still visible). The use of default layouts is another, as is the usefulness of customization for different specialties. We did not detect any degree of information distortion in transmission, but the study is not complete. Likewise users either detected and mentioned omissions, or did not mention them but made correct diagnoses in any case. Times taken were significantly shorter than in case review in which the user had to compose their own interface, as is expected.

E.1.4 Study Four: Testing Clinical Reasoning with Composable and Conventional EHR Approaches

Measure	Definition	Collection and Analysis
Diagnostic accuracy	Essential diagnostic elements used by clinician compared to a reference standard	From recordings and data entry
Information completeness	Percent of essential information elements used	Screen recording, observation notes

Measure	Definition	Collection and Analysis
Error rate	Number of errors made, if applicable, with respect to a reference standard	Screen recording, observation notes
SMMi measure	Proportion of overlap in data elements used by 2 users	See Mamykina's SMMi
Time spent on task	Total time user spent completing the task, and time on subtasks.	Screen capture; counted in seconds.
Number of screen transitions	How many times the user switched from one screen to another.	Screen recording, raw count
Number of mouse movements	Number of movements by mouse	Screen recording, raw count

This study was carried out in Fall 2019 with eight subjects in the Columbia University simulation center. Subjects were presented with a stressful interruptive scenario in which two patients come in with variable symptoms, and subjects were required to switch between EHR records of the two patients. Screen recordings and observations at the time showed that depending on the user's EHR practices, interruption could be more or less disruptive. For example, one user steadfastly finished order entry even though the patient was calling for attention, while others in the same part of the scenario dropped the entry in order to attend to the patient and then had to return. Technical glitches with the conventional system affected our ability to collect data, and so it was determined that the 4 subjects using the conventional system should be repeated at a later time. In the spring of 2020 our plans for doing this were postponed due to the shutdown of most of the non-clinical facilities and overloading of emergency staff (from which our subjects were drawn) due to Covid19.

Study Five: Mapping EHR navigation
Use of Timebelt visualization(29) (30) to analyze task and subtask flows is useful as a technique to assess and improve usability and in a comparison of the experimental and usual EHR use for the same case showed decreased screen transitions for the experimental UI and patterns of repetitious navigation in the commercial EHR, as found in some of our previous work. In the simulation study high-stress scenarios with actors were effective in forcing back and forth navigation in the EHR and simulating stressful ordering tasks; data analysis is in progress.
The Sunburst visualization(29) method is effective in providing complete but comprehensible maps of the navigation structures in 3 different EHRs, providing a means of comparison both visually and quantitatively in our formulae for DFI (Display Fragmentation Index), and also when programmed as an interactive sunburst, provides a design pattern for navigation, which can be used (with appropriate functions) to streamline workflows. In combination with MedWISER it may be used for element selection from the conventional system and placement juxtaposed in the MedWISER system; with further development this would provide an adjustment tool to aid workflow redesign. By selecting needed elements from the complete overview the sunburst provides, one could juxtapose elements which are normally far apart in the usual EHR, reducing steps and providing easier data review.

E.2 Outcomes

E.2.1 Study One: Cognitive Load, Screen Switching, and Working Memory
Observations so far confirm the value of being able to display all relevant data on the same screen, for user cognition and decision making. Two issues are presentation of item selection when the record is extensive, and individual preferences for specific presentation types (e.g. Fishbone v. plotting).

E.2.2 Study Two: Assess Information Needs and Task Performance with Conventional Systems
Several current design patterns pose safety issues.

E.2.3 Study Three: Assessing Composable System Information Sharing Fit to Task

So far we have not found evidence that sharing fosters errors due to lack of omission or error detection. Subjects made correct diagnoses even when the cases contained deliberate errors or omissions. In study 3, the information transfer via composed displays (online studies) the findings so far show that users need not explicitly recognize omissions or errors in order to achieve correct diagnoses. Perhaps this is revealing of additional unknown aspects of clinical reasoning – that clinicians may observe and discount data in the course of reasoning due to other case factors being more salient, or perhaps due to other unknown factors about clinical reasoning itself. Times taken for case review of composed cases were, as is to be expected, shorter than when users had to compose displays themselves.

E.2.4 Study Four: Testing Clinical Reasoning with Composable and Conventional EHR Approaches with high stress and interruptions

Study 4 (simulation center study) demonstrated that use of standardized patients in a carefully considered scenario with simulation-trained staff, is effective in simulating EHR use interruptions and back and forth use of the different patient records in the EHR. User engagement was extremely high, as per their debriefing statements, causing stresses despite the knowledge of simulation.

Analysis of the crossover study findings to date show that concerns about display fragmentation are widely expressed by clinicians, who all recognize the potential for composable displays to remedy the issue, at least partially. The results of the mapping and timebelt analyses(29, 30) show the greater degree of fragmentation for conventional systems, in typical tasks. These methods of analysis are likely to prove useful in other use cases and task analyses, providing easily understandable but expressive visualizations and metrics. The Display Fragmentation Index (DFI) provides a means of comparison between EHR systems, tasks, and a method of measuring the success of redesigns (of EHR interfaces and/or workflows) which seek to reduce display fragmentation(29). Covid delayed some activities due to difficulty accessing facilities and health professionals.

<u>Other outcomes</u>

New visualizations developed included the use of sunburst visualization to represent EHR navigation trees for both analysis and as a possible additional navigation tool in interfaces, experimentation with hGraph clinical data visualization(31), and other forms.
New methodologies for this type of research included the refinement of remote usability testing methods with eye tracking and usability software screen recording.
Researchers were Invited to give talks in Europe and formed linkages with other labs; collaboration with companies and possible openEHR(32) work is being explored. The composable approach is one of the options for technology development in a second AHRQ grant on Covid handling by a safety net hospital. The team conducted a panel with NASA and others working with user-controlled software development approaches.

E.3 Conclusions

We confirmed that mapping EHR navigational structures and using specific and interactive visualizations to depict them and quantify differences has value in studying and improving EHR design, particularly as it relates to display fragmentation and cognitive load. Think-aloud studies confirm the usefulness of composable interfaces in easing user mental processes, but there are still needs for specific interaction design tweaks. There was considerable interest in improving design, expressed by most of the users tested, and in our presentations at conferences and informal discussions with stakeholders, as usability has emerged as a major reason for EHR stresses on clinicians.
A major issue that was brought to the surface in our AMIA 2018 presentation was the vigorous discussion of how to bring researchers and vendors closer to work together. We are currently exploring new ties with vendors.

E.4 Significance

As we theorized, use of a composable approach appears to have advantages for relieving cognitive load, improving fit to task, and possible efficiency and time savings. Safety and usability are critical for effective use of EHRs and to address the physician burnout issue, with close to 50% of US physicians stating they experience aspects of burnout and have difficulty with EHRs impacting their practices and time. Implementation of this approach into working electronic health records will be encouraged by providing UI/UX design patterns open source to vendors. 'Design patterns' refers to reusable code or interaction features that can be used to solve problems commonly found in programming or interaction design. Providing short videos showing the new interaction design and how it is used allows others to adopt the pattern, and benefit from the improved interaction for specific tasks(33-35). The development of methods to characterize (qualitatively and quantitatively) the degrees of fragmentation present in current EHRs allows comparison between products, processes, and measurement of improvements. Our findings confirmed previous work showing major design impacts of current design in increasing cognitive load of clinicians and the need for improvement in design. Refinement of remote testing methods (possibly including remote eye tracking) contributes to usability testing methods.

The advent of Covid19 has called attention to the need for and advantages of rapidly changeable composable IT systems which can rapidly integrate diverse information sources for both care and pandemic planning, and to this end we have submitted a Viewpoint to Nature Partner Journals Digital Medicine. Future work will use the MedWISER features to develop tools for handling pandemic resurgence.

Moving forward, we envisioned a two-pronged plan. The first will continue to use MedWISER as an experimental EHR platform. Our studies surfaced a host of challenges that can include changes to the model and opportunities for training clinicians to make better strategic use of the new interaction features embodied in a composable platform. There are many questions that remained to be answered. The second arm of the research program will be to continue to work with institutions to implement MedWISER as an alternative model of interaction. It will sit on top of their existing EHRs and provide the full complement of functions, but also offer a unique and perhaps, creative ways to use patient information more productively.

The use of composable interaction design for EHRs has promise to solve some problems in ease of use, fit to task, and safer interaction. Further work is needed to confirm these effects. We anticipate possibly releasing a set of design patterns(33-35) for vendors to adopt, open source.

F. PUBLICATIONS AND PRODUCTS FROM THE GRANT

- Roman LC, Ancker JS, Johnson SB, Senathirajah Y. Navigation in the electronic health record: A review of the safety and usability literature. *J Biomed Inform*. 2017;67:69-79. doi:10.1016/j.jbi.2017.01.005 PMID: 28088527
  Much cited overview of navigation structures and issues in electronic health records.
- Senathirajah Y, Borycki EM, Kushniruk A, Cato K, Wang J. Use of Eye-Tracking in Studies of EHR Usability - The Current State: A Scoping Review. *Stud Health Technol Inform*. 2019;264:1976-1977. doi:10.3233/SHTI190742 PMID: 31438436
  Overview of eye-tracking methods and use in EHR usability studies.
- Senathirajah Y, Wang J, Borycki E, Kushniruk A. Mapping the Electronic Health Record: A Method to Study Display Fragmentation. *Stud Health Technol Inform*. 2017;245:1138-1142. PMID: 29295280
  Describes a method to map EHRs to allow understanding and comparison of display fragmentation in different EHRs.
- Kushniruk A, Senathirajah Y, Borycki E. Towards a Usability and Error "Safety Net": A Multi-Phased Multi-Method Approach to Ensuring System Usability and Safety. *Stud Health Technol Inform*. 2017;245:763-767. PMID: 29295201
- Borycki E, Senathirajah Y, Kushniruk AW. The Future of Mobile Usability, Workflow and Safety Testing. Stud Health Technol Inform. 2017;245:15-19. PMID: 29295043

- Kushniruk A, Senathirajah Y, Borycki E. Effective Usability Engineering in Healthcare: A Vision of Usable and Safer Healthcare IT. Stud Health Technol Inform. 2017;245:1066-1069. PMID: 29295265
- Saiku, I., Senathirajah, Y., Borycki, E. M., Kushniruk, A. W., Malik, U., & Wang, J. (2017). Remote Usability Testing Method for an EHR Platform. In AMIA.
- Collins S. Deep Dive: Evaluation Methods for Electronic Health Records. Stud Health Technol Inform. 2016;225:759-761. PMID: 27332332
- Kushniruk A, Borycki E, Senathirajah Y, Hudson D. Are EHRs "Overloading" Health Professionals? Issues, Advances and New Directions from Cognitive Science and Usability Engineering. *AMIA Annu Symp Proc.* 2017
  Highly attended panel presenting different aspects of cognitive load resulting from EHR design.
- Senathirajah Y, Kushniruk A, Patrick J, Koppel R, Borycki E. Immediate Adaptability. *AMIA iHealth Conference Panel.* 2017

Submitted:
Senathirajah Y, Borycki EM, Kushniruk A, Kaufman D, Fawcett J, Cato K. Going Viral: meeting pandemic needs with rapidly evolvable and shareable information systems. Submitted to Nature Partner Journals Digital Medicine July 2020.

Yalini Senathirajah, David Kaufman, Kenrick Cato, Elizabeth Borycki, Andre Kushniruk. Characterizing and visualizing display and task fragmentation in the electronic health record: methodological approaches. Submitted to JMIR Human Factors, June 2020.

In preparation:
Study Design to test safety effects of composable EHR interaction design. Senathirajah Y, Borycki EM, Kushniruk A, Kaufman D, Fawcett J, Cato K. Submitting to JMIR Protocols.

Design Patterns for EHR optimization. Senathirajah Y, Borycki EM, Kushniruk A, Kaufman D, Fawcett J, Cato K. Journal undetermined as yet.

Comparative clinical reasoning and cognitive effects of conventional versus composable EHR interfaces.

Eye tracking study of clinicians using a conventional EHR for five clinical tasks.

Simulation study of interruptions in an ED setting.

Talks

2015 HITlab, New York city (invited, not for profit healthcare technology group): Designing for Doctors: R01 for Designing a better EHR
2015 Partners Healthcare informatics seminar (invited)
2015 Center for Behavioral and Cardiovascular Health, Columbia Medical School. (invited)
2016 Grand Rounds, University of Buffalo medical school, (invited)
2016 Informatics seminar, New York University School of Medicine (invited)
2016 Downstate research disparities group seminar (invited)
2016 Informatics Seminar, University of Pittsburgh department of biomedical informatics, (invited)
2016* Arcia A, Cato K, Ceber RM, Senathirajah Y, Yoon S. Visualization of Patient-reported Outcomes, Didactic Panel. Proc. AMIA Annual Fall Symposium, Chicago, Illinois, Nov 12-16, 2016.
2017* Senathirajah Y, Kushniruk A, Patrick J, Koppel R, Borycki E. Immediate Adaptability. Panel S10. Proc. AMIA iHealth 2017 Clinical Informatics Conference, Philadelphia, PA, May 2-4, 2017.
2017* Kushniruk A, Borycki E, Senathirajah Y, Hullin D. What Will Be Required to Make Sure Healthcare IT Actually Does What is Expected: Technical and Legal Requirements and Issues. Panel. 16th World Congress on Medical and Health Informatics (Medinfo 2017)—Precision Healthcare Through Informatics. Hangzhou, China, August 21-25, 2017.
2017* Kushniruk A, Borycki E, Senathirajah Y, Hudson D. Are EHRs "Overloading" Health Professionals? Issues, Advances and New Directions from Cognitive Science and Usability Engineering. Panel S74. AMIA Annu Symp Proc., Nov 2017, pp. 298-300.

2017 Use of research grade low cost EEG headsets – demonstration to students in Arthur Ashe program, NYC.
2017 Northwell Health Feinstein Institute, Long Island NY. (invited)
2017 Brown medical school, Providence RI. (invited)
2018* User Control of Electronic Health Record Design and Diagnostic Reasoning (one of 6 finalist chosen abstracts of 148 submitted), Diagnostic Error in Medicine (DEM) 11th International Conference, New Orleans, LA
2018 Keynote Speaker: New Clinician-Controlled Composable Approaches to Health IT. International Conference on Info Tech ICIT 2018, Bhubaneswar, India
2019 Invited Talk: Novel Approaches to Health Information Technology. Intelligent Systems Program, University of Pittsburgh, February 22.
2019 Invited Talk: New approaches to EHR system design. Universite de Lille, Lille, France

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