Understanding Clinician Information Demands and Synthesis of Clinical Documents in Electronic Health Record Systems

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Dedication

I appreciatively dedicate this thesis to Jesus Christ- my ever-loving, never-failing creator, counselor and savior; Folashade- my breathtakingly beautiful wife, best friend, soul mate, and greatest fan; Eniife- my adorable one-year old daughter, personal assistant, and play 'buddy' who never ceases to make me smile; Jide and Rhoda- my parents who constantly love and encourage me towards great achievements; Arinola and Sola- my parents-in-law who tirelessly shower me with unreserved love and support; Toyin- my sweet sister-in-law; Jide Jnr., Temitope, Kingston and Victor- my amazing siblings; Akinleye and Bunmi- my fantastic brothers-in-law; and my affectionate friends spread across the US, UK, Canada, Norway and Nigeria.

Table of Contents

List of Tables

List of Figures

CHAPTER 1

INTRODUCTION

1.1 Electronic Health Record Systems and Increased Information Availability

Research on effective management of multimodal clinical data generated and used during patient care, including automated tools that enable efficient documentation, archival and retrieval of patient information, and solutions to reduce inflated healthcare costs while improving the quality of care increasingly refer to the implementation of health information technology (HIT) to address these issues (1-3). Recent federal legislation, specifically the American Recovery and Reinvestment Act (ARRA) and the Health Information Technology for Economic and Clinical Health (HITECH) Act, fiscally support the adoption of electronic health record (EHR) systems as HIT solutions that can positively impact healthcare quality at different levels of clinical practice (3,4). According to David Blumenthal, in the last quarter of 2009, the US Department of Health and Human Services (DHHS) Office of the National Coordinator for Health Information Technology (ONC) allocated approximately $2 billion to initiatives that would promote Meaningful Use of EHR systems by healthcare providers and support the development of advanced electronic health information systems (5).

The Meaningful Use of EHR systems require that the technology should support health information exchange and interoperability, electronic prescribing, and automated reporting of quality performance, in addition to other functionalities such as active medication management and clinical decision support (6). Despite monetary incentives provided by the Centers for Medicare and Medicaid Services (CMS) to eligible physicians and hospitals on their successful implementation of EHR systems according to the Meaningful Use criteria (7), individual clinicians and health care organizations have been reluctant to adopt these systems due to reported problems with costs of system-wide implementations, disruptions in clinical workflow, and poor design of computer graphical user interfaces (8,9). As an illustration, in a study by Rao et al., they found that physicians in small practices had a low rate of EHR system adoption and were particularly concerned about the relatively large investments required to implement them and the likelihood of acquiring a system that integrated poorly with their work processes or that might become obsolete in the near future (10).

As defined by the Health Information and Management Systems Society (HIMSS), “the 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” (11). EHR systems provide increased access to a vast amount of electronic structured and text-based clinical data which, asides from satisfying the information needs of clinicians, can improve communication among healthcare providers and facilitate the aggregation and analysis of relevant patient information for more accurate clinical decision-making (12). Qualitative and semi-quantitative information on clinical episodes and various medical reports are typically recorded as narratives in EHR clinical documents as a means to articulate clinical details and other peculiarities of the patients' health-related events and potential ambiguity characterizing the clinician's understanding of clinical scenarios (13,14). EHR clinical documents are often lengthy and contain significant data redundancy and information overload, thereby leading to difficulties with navigation and information synthesis when reviewed by clinicians during time-constrained patient care (15-18). According to Feblowitz et al., risks associated with information overload during clinicians' synthesis of EHR clinical documents include unnecessary anxiety, increased chances of missing vital information, communication failures and impaired clinical decision-making (19). Other challenges associated with the effective use of EHR clinical documents are highlighted in figure 1.1.

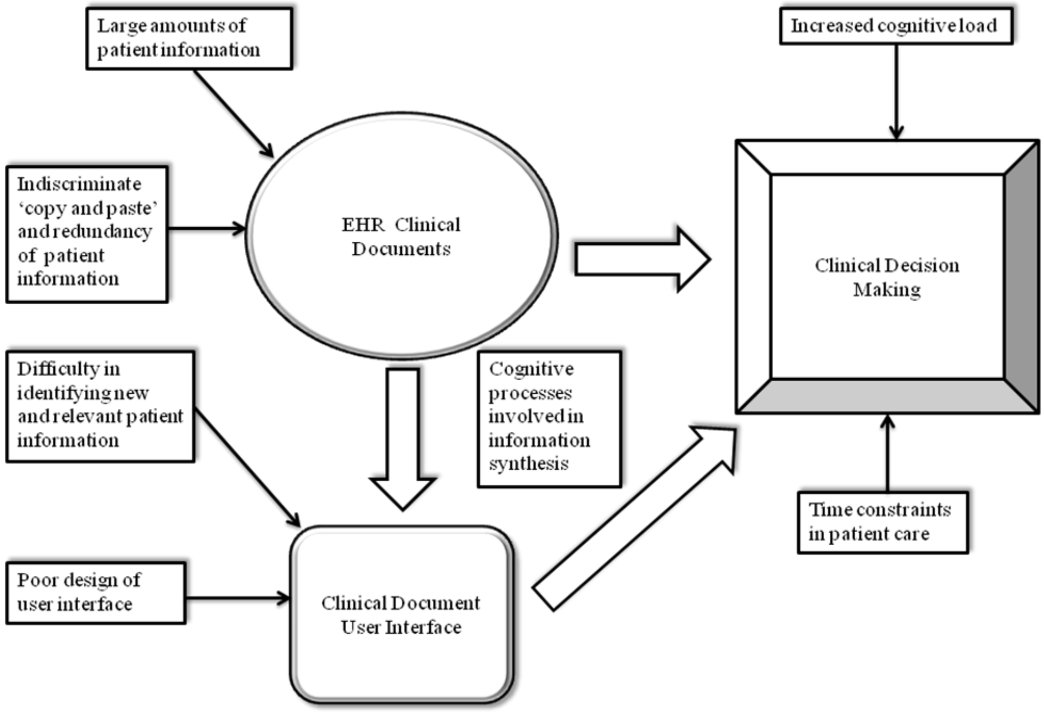

Figure 1.1: Challenges to Synthesis of EHR Clinical Documents

1.2 Cognitive Overload and EHR Clinical Document Visualization

During patient care, clinicians dedicate substantial cognitive resources to constructing mental models representing their patients' conditions by aggregating congruent evidence and resolving contradictions, and generating hypotheses and inferences using their clinical domain knowledge and prior clinical experiences (20-22). Having to process large amounts of patient information and problems with identifying specific clues or unraveling critical clinical facts contained in the EHR may warrant the use of more resources than can be afforded by the clinician's cognitive 'capital' during clinical care (23,24). The short-term or working memory (WM)- the 'central processing unit' of the human cognitive architecture- can only process a small pool of informational elements at a given instance; this limited capacity can result in cognitive overload and inefficiency when clinicians review overwhelming amounts of text in EHR documents (25,26). Cognitive load theorists explain that eliminating activities not directly related to information processing (e.g. formatting a disorganized document) and optimizing the way information is presented can considerably reduce the potential cognitive burden experienced in the WM when learning complex narratives (27,28). For example, Koopman et al.'s study on physician efficiency and accuracy in accessing data for diabetes management revealed that presenting information in a concise manner to physicians can help them deal with information overload, and that when physicians spend too long searching for information of interest, they are inclined to do without the information or re-order the investigation necessary to fill the information gap (29).

Design principles employed in user interfaces for EHR systems often restrict effective presentation of text within clinical documents, and the ability to easily distinguish between new and redundant patient information can be compromised due to poor document organization and visualization techniques (30,31). According to Van Vleck et al., the presentational format of quantitative information in the EHR can be easily improved by simple tables and sophisticated graphical summaries of, for instance, longitudinal laboratory data (32). However, the development and use of interactive visualization tools in EHR systems to provide cues and facilitate clinicians' accurate comprehension of text-based clinical documents still remains largely unaddressed (33).

1.3 Time Constraints and EHR Clinical Document Synthesis

Despite the growing advocacy for adoption of EHR systems, potential benefits are often eclipsed by increased physician time expenditure associated with using these systems (9,34). Computerization of the patient record and documentation of clinical information has elicited mixed responses regarding clinician time trade-offs between capturing patient details at the point of care and achieving time-intensive and meaningful interactions with patients. As stated in several studies, possible time-savings when documenting clinical details arising from electronic copying and pasting of unchanged clinical information is frequently negated by needless data redundancy, possible propagation of errors due to clinicians' duplication of patient data, and undue 'plagiarism' which could lead to unintended consequences (35-37).

Time constraints experienced by clinicians during patient care have been cited in various studies (38-41). As stated in David Mechanic's article on the future of primary care, "physicians persistently report time pressures and insufficient time for patients and are particularly dissatisfied when their remuneration depends on successfully constraining the clinical choices they can offer their patients" (42). Cooper et al. identify time constraints as obstacles to accurate diagnoses and appropriate treatment of pediatric patients (40). Furthermore, the continuous need for clinicians to review multiple EHR clinical documents during the typical 15 – 20 minute long out-patient visit increases the likelihood of overloading their WM in the short duration available for complex cognitive activities related to patient care (43-45).

1.4 Think-aloud Protocol and Cognitive and Usability Studies

The process of diagnosing and managing clinical conditions, as an example of human reasoning and problem-solving, comprises an array of ongoing information processing activities residing in the clinician's mind. How does an observer gain direct access to these activities for researcher purposes? The think-aloud (TA) protocol is a recognized method for gathering rich qualitative data related to the general human skill of verbalizing one's thought processes (46,47). Verbalized perceptions and related behavior identified by use of a TA protocol can be linked directly to reasoning strategies, information processing and overall cognition of an individual as observed while s/he performs certain problem solving activities (48-50). It is common knowledge that thinking aloud during real-world interactions may be met with unpleasant reactions from observing individuals (e.g. listening to a cashier at the grocery store check-out verbalize all his/her thought processes related to your grocery choices may not be 'well-received') (47). However, given the same scenario without any reactions from observers, recording these thought processes can provide valuable data which, when analyzed, can help explore the cashier's reasoning associated with the check-out process. The TA protocol is a scientific method useful in investigating cognitive activities associated with task accomplishment, variations in information processing techniques across a continuum of career expertise, and the impact of specific factors on cognition and problem solving capabilities (26,51-54).

In addition to applications in cognitive psychology, the TA protocol is a major technique used in usability evaluation (55-57). Usability evaluation refers to the assessment of user satisfaction, performance and problems with using a particular product (58,59). According to Jaspers et al., in usability evaluation studies based on the TA protocol, users verbalize their thought processes as they simultaneously interact with specific products, systems or interfaces as stipulated by pre-established task scenarios, and analyses of the verbalizations "provide insight into problems actually encountered by users and the causes underlying these problems" (60). Knowledge of usability issues and elements of user-computer interaction related to specific tasks can assist in framing system design strategies required to better support characteristic cognitive processes and behavior of intended users (30).

1.5 Objectives

Despite advances in cognitive research within health informatics, fundamental understanding of clinicians' cognitive processes used in synthesizing text-based EHR documents has been scarcely addressed. Unfulfilled demands for critical patient data and poorly organized clinical narratives possibly underlie minimal synthesis of EHR clinical documents by clinicians during patient care (61,62). Inefficiencies including redundant test orders and increased risk of missing vital diagnostic or therapeutic details may arise when EHR clinical documents are not thoroughly reviewed by clinicians (63). How then can EHR clinical documents be better visualized to support clinicians' information synthesis in the context of clinical care? A useful approach to addressing this question is studying how clinicians think and make decisions while performing clinical tasks that require review of electronic clinical text, and to integrate the knowledge gained towards improving clinical text display (31,52). In addition, insight on the relationship between existing factors in the practice environment and clinicians' cognitive processes may shed more light on potential barriers to effective synthesis of EHR clinical documents at the point of care.

In a collection of three studies incorporating fundamental principles in clinical informatics, cognitive psychology and human-computer interaction, the TA protocol, combined with other qualitative and quantitative methodologies, was utilized to investigate clinicians' cognitive processes associated with EHR clinical document synthesis in the context of patient care and the potential effects of enhanced data visualization on processing of these documents. In the ensuing chapters, details of these studies focus on systematically achieving the following objectives:

- Experimentally deriving the information demands and cognitive processes employed by clinicians while synthesizing clinical documents in EHR systems
- Examining the impact of time constraints on cognitive processes of clinicians related to EHR clinical document synthesis during ambulatory care

- Evaluating the effects of a novel visualization tool and related text-based cues on clinicians' synthesis of EHR clinical documents

These three studies serve to fill fundamental knowledge gaps in our understanding of how clinicians interact with EHR systems when using clinical documents in the practice context and can help future EHR system user interface design for clinical text with the ultimate goal of supporting clinicians' consumption of patient information, improving patient care, and promoting clinician satisfaction with these systems.

CHAPTER 2

A QUALITATIVE ANALYSIS OF EHR CLINICAL DOCUMENT SYNTHESIS BY CLINICIANS

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Clinicians utilize EHR systems during time-constrained patient encounters where large amounts of clinical text must be synthesized at the point of care. Qualitative methods may be an effective approach for uncovering cognitive processes associated with the synthesis of clinical documents within EHR systems. We utilized a think-aloud protocol and content analysis with the goal of understanding cognitive processes and barriers involved as medical interns synthesized patient clinical documents in an EHR system to accomplish routine clinical tasks. Overall, interns established correlations of significance and meaning between problem, symptom and treatment concepts to inform hypotheses generation and clinical decision-making. Barriers identified with synthesizing EHR documents include difficulty searching for patient data, poor organization, redundancy, and unfamiliar specialized terms. Our study can inform recommendations for future designs of EHR clinical document user interfaces to aid clinicians in providing improved patient care.

2.1 Introduction

The transition from paper-based media to EHR systems, supported by recent national mandates for the implementation of HIT, provides unprecedented access to vast amounts of diverse clinical data at the point of care. However, clinicians are often challenged by the 'disconnect' between current implementations of EHR systems and the complexities of clinical decision-making, including the organization of text-based clinical information within these systems.

Medical cognitive science emphasizes the complex nature of clinical reasoning and the significance of knowledge representation in medical decision-making. An ongoing range of cognitive processes is utilized by clinicians in constructing mental models that aptly reflect clinical scenarios and assist in making effective clinical decisions (64).

Over the last decade, an important focus of informatics research has been the development and evaluation of EHR user interfaces such that they are equipped to adequately satisfy clinicians' information needs to effectively reduce the cognitive load of information retrieval and improve the learning process involved in using these systems (65-67). Improving our understanding of clinicians' cognitive processes, specifically those surrounding the use of text-based EHR clinical documents, could improve user-centered cognitive models and aid the design of clinical document user interfaces (1,20). The objective of this study was to gain insight into cognitive processes of clinicians as they synthesize information from an EHR prototype, specifically concentrating on the use of text-based clinical documents as primary data sources.

2.2 Background

2.2.1 Information Overload within EHR Systems

In clinical practice, complex data processing remains an integral aspect of problem-solving strategies utilized by experts, sub-experts and novices alike (20)(26). Timely access to patient information relevant to routine and emergency clinical processes determines the clinician's familiarity with clinical concepts and the context of clinical situations. EHR implementations provide clinicians with rich and extensive patient-specific information from a large number of sources in multiple and different formats (68)(69). Narratives (free text) recorded in the EHR by clinicians (physicians, nurses, and other healthcare providers) as they care for patients are contained in documents that have significant information over and above the structured nature of data such as vital signs and laboratory results. These EHR documents allow for precise representations of clinical scenarios and better elaboration of clinical uncertainties and details compared to structured data. However, the quantity of information within these documents can be overwhelming, thereby posing cognitive challenges to clinicians reading and using these documents. Therefore, the issue with information accessibility at the point of care is transforming the balance of information from 'having too little' to 'having too much' (70).

One factor responsible for excessive information within EHR clinical documents is the frequent and often indiscriminate ‘copying and pasting’ of redundant patient information in an attempt to accurately capture pertinent details from previous clinical encounters and provide sufficient information for billing purposes. Despite the time-savings and administrative benefits facilitated by the ‘stand-alone’ clinical encounter documents, transferring information from one clinical document to another may propagate unidentified errors that could have adverse effects on patient management (15).

2.2.2 Cognitive Demands at the Point of Care

Assuming a cognitive network of humans and computers as the fundamental unit of analysis, some experts draw attention to the dynamic and radical changes in a given professional or social environment following the introduction of new computer technology, as well as the impact these changes may have on the cognitive demands on accomplishing routine tasks in this technologically changed environment (71). To mitigate possible increases in cognitive demands associated with learning HIT, it is important to consider cognitive activities and information processing techniques at the point of clinical care and the extent to which these activities can be influenced by the implementation of EHR systems.

During a primary care visit, for instance, the clinician has about 15 minutes to establish patient rapport, review free text and structured documents within the EHR, perform an adequate physical examination, communicate an overall clinical impression, and complete orders and prescriptions necessary to manage the patient's condition (72). Within this time-constrained and considerably stressful patient encounter, the clinician's cognitive efforts are devoted to consuming relevant information from previously documented clinical encounters in order to construct a mental model representative of the patient's situation. Constructing this mental model becomes even more taxing when an unfamiliar patient's medical record is to be reviewed during a first-time clinical encounter.

Synthesizing EHR clinical documents requires allocation of cognitive resources to processing both novel and familiar information. According to experts, no more than two or three novel information elements can be processed adequately at any one time by the WM. Therefore, when clinicians review multiple clinical documents associated with unfamiliar clinical scenarios, the WM likely experiences a cognitive burden that may have detrimental effects on professional motivation and productivity.

In some instances, cognitive resources that should be employed in establishing clinician-patient rapport and managing the patient's condition may be devoted to restructuring poorly formatted data within EHR clinical documents to facilitate better information synthesis. Leveraging the cognitive load theory, cognitive load associated with reviewing large amounts of EHR clinical documents may depend on how information is presented to the clinicians and the range of actions required to access the information in a format that is easy to consume (Figure 2.1) (25,72). If patient information within an EHR clinical document user interface is presented in a poorly organized fashion that warrants laborious 'browsing' to derive critical data, system users may experience frustrations and have reduced motivation for thoroughness, resulting in a increased propensity for erroneous clinical judgment.

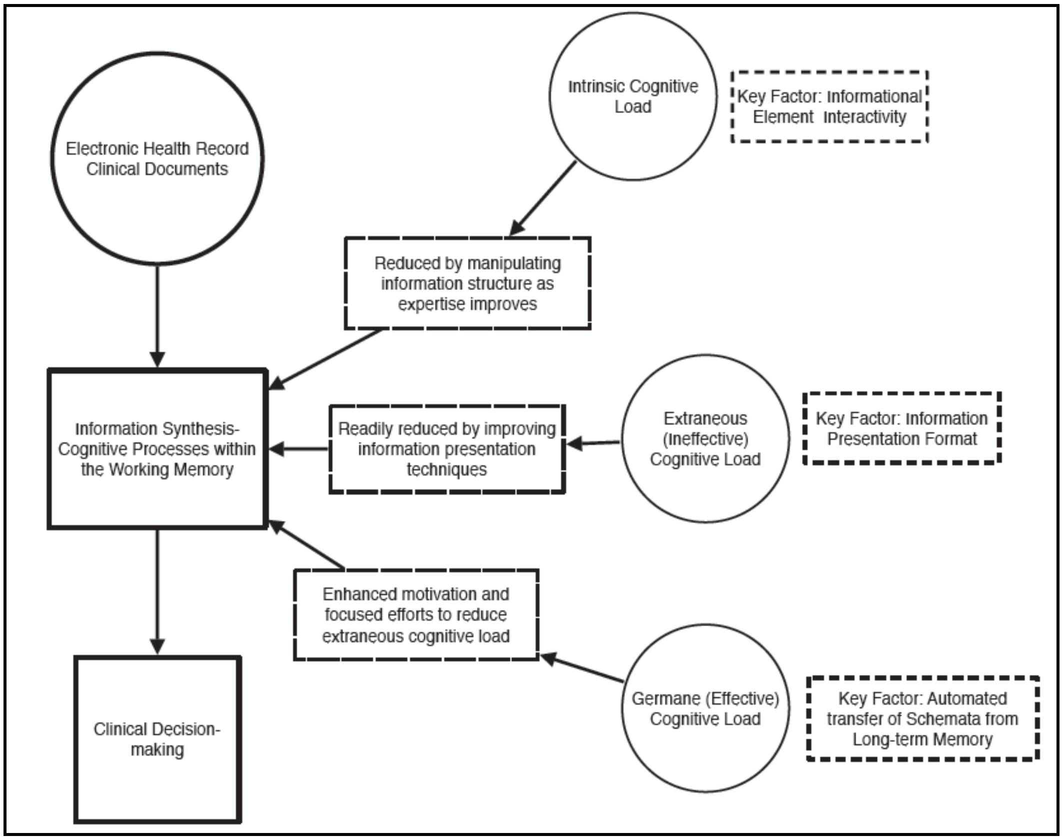

Figure 2.1: Application of Cognitive Load Theory to EHR Clinical Document Synthesis

2.2.3 Think-aloud Protocol

Critical thinking can be represented as sequences of thoughts or cognitive states separated by processing activities (47) . The TA protocol, as a scientific method through which human cognitive activities can be made verbal, was first highlighted in the mid 1940s

(49,73). The principle of the TA protocol is to obtain data in the form of verbalized statements in order to investigate cognitive processes relative to certain human activities. TA protocols typically use simulations of problem-solving tasks to elicit verbal reports that reflect human cognitive processes. Clinical case studies and patient scenarios have been recommended as suitable approximations of realistic clinical practice involving iterative interpretation of previous clinical data in the light of new information. These clinical scenarios are inexpensive to develop, and they allow for predetermination of clinical tasks and control over interruptions expected in the real world (50).

Based on principles of information processing theory, the TA protocol attempts to reveal and describe which information is being analyzed and how the information is structured or reconfigured within the WM during a problem-solving activity (50,74). Evidence that supports the use of the TA protocol includes the fact that (a) human cognition refers to a sequence of internal states typically transformed by information processing, (b) these sequences of internal states can be externalized through verbalizations, and (c) recently acquired information which has become the focus of an individual's concentration can be accessed directly as verbal data (50,75).

2.3 Methods

Clinicians were observed as they interacted with electronic clinical documents within a prototype EHR system which had functionalities to select specific documents, sort them out by date, and to copy sections of a particular document unto a new note. These clinicians were asked to verbalize their thought processes while reviewing clinical documents in the context of accomplishing a set of routine clinical tasks. The think-aloud protocol audio recording provides qualitative data that was synchronized with the screen display and navigation on the EHR system screen captured by a video camera in a controlled environment (76) (Figure 2.2). Also, a content analysis of the clinicians' verbalizations while accomplishing the clinical tasks was performed. Approval for this study was obtained from the University of Minnesota Institutional Review Board (Study Number: 1012E93487).

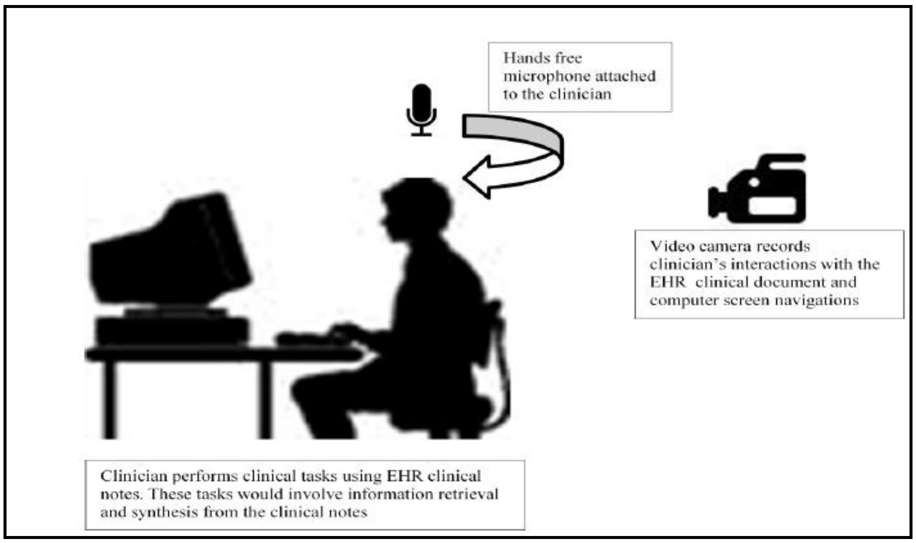

Figure 2.2: Overview of Think-aloud Experiment

2.3.1 Study Sample

A purposive sample of clinical interns was recruited for our study based on similar sample sizes in studies with qualitative analysis of medical cognition and clinical decision-making (30,76,77). We restricted participation in the research to the intern level physicians in order to control for differences in cognitive processes and medical decision-making techniques due to varying clinical expertise.

2.3.2 Experimental Design

Each intern reviewed nine patient records from the Fairview Health Services at the University of Minnesota Medical Center. These records contained free-text documentations of eight to nine office visits related to the management of chronic medical diagnoses such as type 2 diabetes mellitus and essential hypertension. The interns reviewed the records while performing routine clinical tasks within a simulated clinical setting.

With the assistance of two experienced clinicians (GM and TA), we developed clinical practice scenarios requiring ongoing assessments of clinical documents within the EHR system. An example of a clinical practice scenario is given below:

> Ms XXX visited the emergency department (ED) today with a 24hr. history of fever and pain in her right flank. She has vomited thrice since yesterday and still feels nauseated. Her temperature today is 102.4F while her BP is 120/74mmhg. Please develop an admission note for this patient.

As the interns performed the clinical tasks using the patient records within the EHR system, the observing researcher would only interrupt if there were a short (15 – 20 seconds) period of silence in order to prompt the intern to continue ‘thinking aloud’.

2.4 Results

Six clinical interns were observed as they utilized the text-based clinical documents for these controlled patient scenarios. The average length of a scenario observation was 18.96 minutes. The technical expertise of the interns, in terms of EHR system use, ranged from intermediate to professional; each intern was familiar with at least three different vendor-based EHR systems in their clinical rotations. There were 2 male and 4 female subjects in our sample of interns between 26 and 30 years of age. Overall, 853 minutes of observations were transcribed and analyzed using the QSR NVIVO (version 9) qualitative analysis software.

2.4.1 Protocol Analysis

We reviewed all study transcripts to enable familiarity and to identify general impressions from the observational data. Consideration of our study objectives and literature on medical decision-making research and the use of think-aloud protocols resulted in the use of a three-step coding scheme for the analysis of the study transcripts based on recognized frameworks for protocol analysis (50,78-80).

2.4.1.1 Referral Phrase Analysis

As a first step in the protocol analysis, the interns' verbalizations were organized according to various concepts referred to by the nouns and noun phrases contained in the transcripts. The referral phrases identified were used in defining the concepts that constituted the main focus of intern reasoning as they performed the clinical tasks using the EHR clinical documents. The universe of concepts derived from the referral phrase analysis (RPA) constitutes an ontology for the virtual domain of information synthesis from EHR clinical documents (81). In order to ensure the validity of this coding procedure, the researcher continued with the RPA until all concepts within the transcribed data were adequately defined and coded (Table 2.1). During the RPA, when a transcribed statement contained several nouns and/or noun phrases referring to multiple concepts, the statement was coded under all appropriate concepts in order to ensure completeness in the data analysis and to retain the contextual information within the statement. For instance, in the following statement:

> "She has had headaches since last fall. So why does it improve with Levaquin? That's an antibiotic!"

There are words and phrases that refer to the *Symptom* (She has had headaches…), *Time* (since last fall…), and *Treatment* concepts (So why does it improve with Levaquin? That's an antibiotic!).

Table 2.1 Referral Phrase Analysis

Concept	Definition	Example from Transcripts
Action	indicates the performance of an activity	"I'm just *reading about this IBS thing*."
Sign	objective clinical information which may reflect the patient's health status	"Her *blood pressure is 100/70, she's OK*. Temperature- *She's got a fever and her respiratory rate is elevated*."
Symptom	subjective clinical information which may reflect the patient's health status	He's got *shortness of breath* on climbing the stairs, *dizziness, dry cough, headaches*."
Test	investigative procedure related to the patient's health status	"So her diabetes is borderline controlled-- it looks like her *last Hemoglobin A1C was 7.3*."
Time	indicates a chronological reference	"I still feel sort of limited in what I can actually find out about him because I don't know what happened to him *last time when he came in three weeks ago*."
Treatment	therapeutic and/or preventative procedure related to the patient's health status	"Her medications- *Miralax, Sertraline, Aricept. I wonder why she is on Aricept*."
Problem	past or current diagnosis that may reflect the patient's health status	"So, right away, I'm thinking about *pneumonia with sepsis*, or at least some sort of infection."
Value	assessment of the usefulness or importance of clinical information	"Alright that note *was very helpful. It gives us a lot of good information*."
Format	indicates the presentational arrangement and access to clinical information	"I don't really like it when the medication list is like this because, for me, *it's hard to read*."

2.4.1.2 Assertional Analysis

In the second coding step, assertions made by the interns were coded based on how they determined relationships between verbalized nouns and noun phrases as they performed stated clinical tasks using the EHR clinical documents. The assertional analysis (AA) facilitates the combination of the concepts identified in the RPA and the existing relationships between these concepts in order to understand the epistemology (the nature, validity and limitations) of information synthesis from EHR clinical documents as reflected by the study participants (50,81). Each statement under the RPA concepts were exclusively coded based on the whether the intern established any significative, implicative or causal relationship between concepts in the statement (Table 2.2). In contrast to the RPA, the AA did not involve multiple coding of the same statement as each statement was assessed for the dominant relationship/assertions between concepts. For example, in this statement:

> "I like that I see some of his past medical history like substance abuse."

Despite indicating that a past medical history of substance abuse is present in the patient's record (implicative assertion), the highpoint of the statement is that the intern asserts the relevance of the past medical history to information processing; thus there is a relationship of significance (significative) between the past medical history (*Problem*) and the intern's access to clinical information (*Format*).

2.4.1.3 Script Analysis

Script Analysis (SA), the final step in the protocol analysis, was carried out in order to determine the overall configuration of the interns' cognitive activities during the experiments; the transcribed data were collectively reviewed and analyzed based on a reference frame of cognitive operators (78). These operators were defined based on the results of preceding analytic steps (RPA and AA). The SA identified predominant reasoning and decision-making processes involved as the EHR clinical documents were synthesized by the interns (Table 2.3).

Table 2.2 Assertional Analysis

Assertion	Definition	Example from Transcripts
Implicative	relationship of meaning	"So here we see that her hemoglobin A1C has been 7 at her last three visits-- *so that's good. I can see she's taking control of her diabetes*."
Significative	relationship of significance	"She *doesn't have any change in mental status*; she's *got some head trauma*; there's *ecchymosis in the left lateral femur*."
Causal	relationship of cause and effect	"So he's got dizziness, dry cough and a throbbing headache so *what is causing this and where is it coming from*? So, I'm just wondering if some of these are, *some of it could be possible medication side effects*."

Table 2.3 Script Analysis

Operator	Definition	Example from Transcripts
Explain	relates to the rationale for an assumption/course of action	*"So, given her history of diabetes, I'd worry about pseudomonas."*
Assume	relates to making an assumption/hypothesis	*"So it sounds like she probably has … well she could have like, a bleeding ulcer"*
Decide	relates to establishing an opinion/course of action	*"Vital signs: relatively civil, except she has a fever. So, definitely pointing towards an infection."*
Review	relates to considering information attentively	*"He's currently on CPAP."*

To determine interrater reliability, a second researcher (DP) with recognized expertise in qualitative analysis, and who was familiar with the coding scheme, analyzed a subset representing 16% of the transcripts. Overall, the mean agreement between the investigators was 82%. Coding discrepancies between the investigators were discussed and addressed for potential overlaps.

2.4.2 Cognitive Pathway

There was considerable variation in the concepts and assertions identified as each intern reviewed and synthesized EHR clinical notes within the patient records. The three most frequently occurring RPA concepts were *Problem* (24%), *Treatment* (17%), and *Symptom* (13%), and relationships established between these concepts were mostly those of significance (*Significative*, 56%) and meaning (*Implicative*, 29%) (Table 2.4).

Table 2.4 References in Referral Phrase and Assertional Analyses

RPA Concept	Number of References (%)	AA Category	Number of References (%)
Action	62 (2)	**Implicative**	411 (29)
Sign	212 (9)	**Significative**	804 (56)
Symptom	330 (13)	**Causal**	210 (15)
Test	234 (10)	Total	1425 (100)
Time	211 (9)		
Treatment	434 (17)		
Value	234 (10)		
Format	149 (6)		
Problem	602 (24)		
Total	2468 (100)		

Based on patterns of information retrieval evidenced by results of the RPA and AA in conjunction with operators identified in the SA (*Review, Assume, Explain* and *Decide*), we constructed a common cognitive pathway associated with the synthesis of EHR clinical documents by the interns (Figure 2.3).

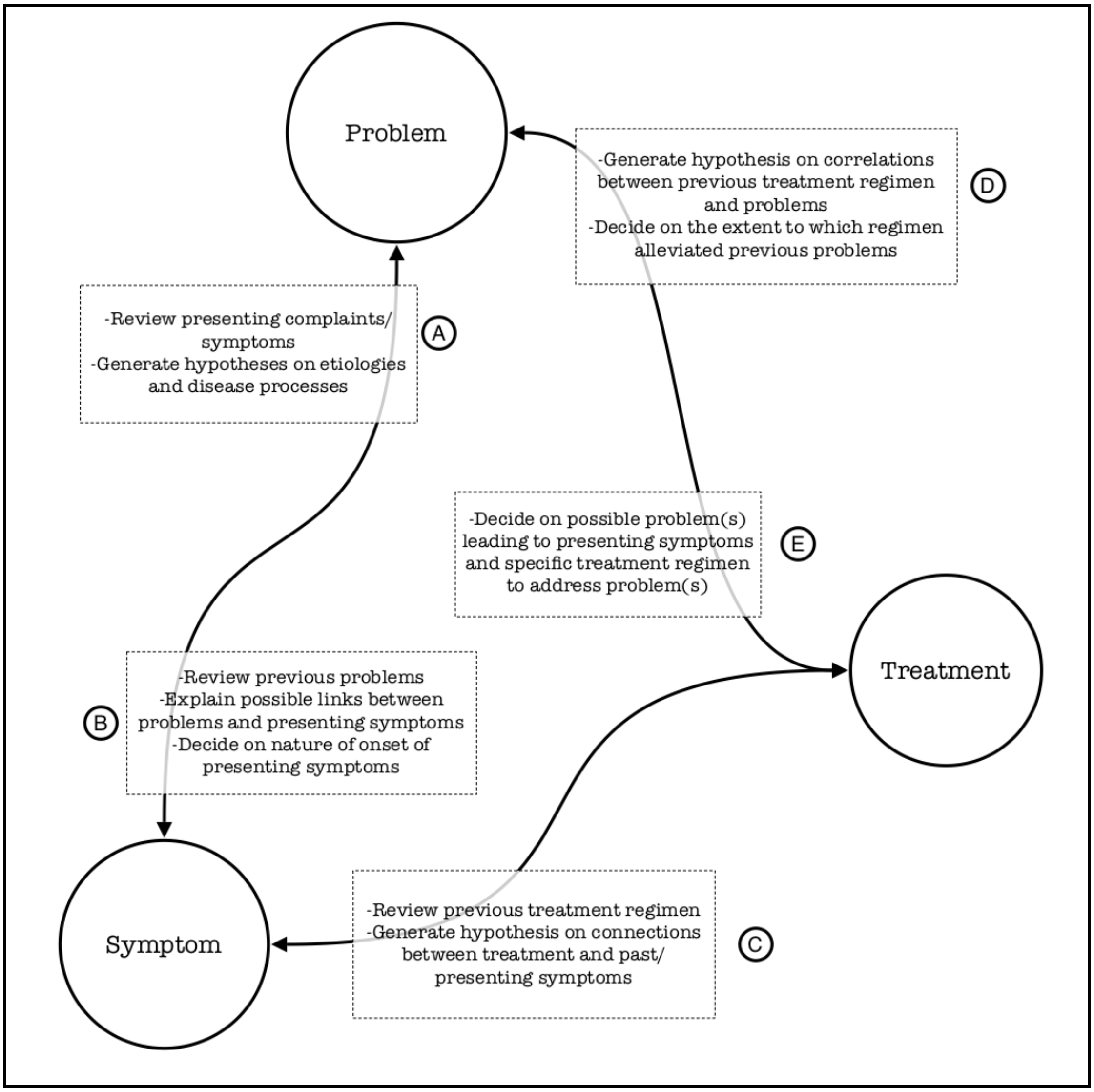

Figure 2.3: Common Cognitive Pathway of Interns Synthesizing EHR Clinical Documents

The pathway begins with attentive consideration of presenting complaints/symptoms and generation of hypotheses on etiologies and disease processes responsible for these complaints (A). This is followed by a thorough review of patient-specific facts regarding previous diagnoses (medical and surgical), familial medical conditions, and medically relevant social habits, towards providing evidence to support the clinician's hypotheses. This process facilitates the establishment of new connections between disease processes and presenting symptoms and distinguishing between exacerbations of previous complaints and the onset of new problems (B). In further clarifying and establishing the clinician's hypotheses, deductive analysis of medications and other treatment regimen is carried out to determine their correlation with past and ongoing complaints and to ascertain the extent to which these interventions alleviate existing problems (C and D). Finally, based on knowledge acquired from previous clinical experience and evidences gathered via information synthesis, the clinician constructs a mental model that summarizes the presenting clinical scenario, narrows the range of possible diagnoses, and decides on specific clinical interventions to address these diagnoses (E).

2.4.3 Content Analysis

In order to identify potential barriers to information synthesis from EHR documents, we performed a content analysis of study transcripts and concentrated on themes related to the consumption of EHR documents (Table 2.5). The main themes from our content analysis included:

Difficulty with Searching for Information: While synthesizing the EHR documents to provide care in line with stated clinical scenarios, clinicians expressed difficulties with searching out vital patient-specific details. Inability to identify pertinent clinical data within EHR documents towards satisfying clinician information demands at the point of care can significantly reduce provider efficiency and the likelihood of them delivering quality healthcare. Some comments related to the difficulty in searching include:

> "So it's not really too obvious what the result was. Let's see… still trying to find out what the pathology said."

> "Am I missing something that is in here and I'm just not seeing it? I still don't see a surgical history."

Table 2.5 References in Content Analysis

Theme	Number of References (%)
Difficulty in Searching for Information	69 (29)
Poor Document Organization	68 (28)
Problems with Redundancy	44 (18)
Unfamiliar Specialized Terms	14 (6)
Inaccurate/Incomplete Data	46 (19)
Total	241 (100)

Poor Document Organization: The general formatting of the EHR documents, including the layout of the sections within the document, largely determined the quantity and quality of information synthesized from these documents. Trending of past medical diagnoses, medications, and laboratory values were particularly difficult due to poor alignment of dates or incongruent organization of relevant patient information (e.g. interns' comments) on reviewing medications and problem lists include:

> "She has a lot of medications. I think it would be even better if they were listed in alphabetical order or some other way that would make them a little bit easier to read."

> "This is kind of messy to read. I think this is better than the other list because it has some start and end dates."

Good versus Bad Redundancy: In most instances, the interns thoroughly reviewed only the most recent document in the electronic patient record and browsed through the rest in search of new information that may be relevant to the clinical task being performed. As highlighted in similar studies (15,69) and suggested by the interns' verbalizations, the redundant information contained in the older documents constituted a significant cognitive burden and resulted in an increase in time and mental efforts required to review the patient records during the TA protocol. However, valuable insights about the overall clinical picture documented in the patient records often depended on the interns' review of the redundant information as noted in statements like:

> "A lot of redundancy in this note. It doesn't flow and make the most sense but it had lots of good information."

> "A lot of these are kind of carried over from the last one, which doesn't always change like social history and stuff like that. So, it's good just to have it in there. But it's not giving me any new information."

Unfamiliar Specialized Terms: Due to the sub-expert clinical experience of the interns, and the diverse medical specialties (e.g., pulmonology, cardiology) represented in the EHR documents reviewed during the TA protocol, some terms and abbreviations specific to these specialties were incomprehensible and could not be synthesized along with other relevant patient information. Although the inability to interpret these terms did not result in misdirected clinical decisions, there was likely an increased cognitive burden associated with processing these unfamiliar terms in addition to other patient-specific information. Statements that revealed the interns attempt at interpreting specialized terms and abbreviations include:

> "So, now she's had two weeks of diarrhea. But it's improved with a BRAT diet. I don't know what that is."

> "Fusion of neck… fusion… neck…I don't know what that is."

2.5 Discussion

To improve the impact of EHR clinical documents on patient care, the organization and presentation of patient information should be in sync with the mental models and expectations of clinicians. Our study provides insights on the cognitive processes associated with synthesis of lengthy text-based EHR clinical documents during patient care. We utilized a think-aloud protocol to explicate the cognitive processes of six medical interns as they synthesized EHR clinical documents towards accomplishing routine clinical tasks within a simulated clinical setting. Our findings reveal that, in creating concise conceptualizations of the clinical scenarios, clinicians often synthesized information related to the concepts of problems, symptoms and treatment, and established mostly correlations of significance and meaning between these concepts. These correlations informed hypotheses generation on etiology and disease processes, and decisions on the most appropriate treatment regimens. These insights also informed the construction of a common cognitive pathway for clinicians and provided a platform for content analysis of the clinicians' cognitive processes to identify barriers to information synthesis from EHR clinical documents.

In addition, knowledge from our research informed the development of recommendations for the design of EHR document user interfaces that can support clinicians' information synthesis in order to reduce existing cognitive burden and generate effective action sequences while performing clinical tasks. These recommendations include:

Cues for Improved Visualization of Sections: Display and organization of information within EHR clinical document user interfaces can effectively reduce the likelihood of missing data necessary for appropriate diagnosis and treatment of clinical conditions. Knowledge from this research suggests that EHR document sections containing information related to the concepts of problem, symptom, and treatment are among the most critical to clinical reasoning and decision-making. Therefore, we recommended that software development efforts and HIT research be devoted to developing and implementing solutions towards visually emphasizing these sections in order to support the critical cognitive activities dependent on access to patient information related to the aforementioned concepts. Examples of possible data visualization aids include, but are not limited to, (a) distinct manipulation of fonts in sections or section headers related to problem, symptoms, and treatment; (b) line-spacing and paragraphing to better organize and distinguish these sections in the EHR document; and (c) color-coded highlighting of section headers within the EHR clinical document user interface.

Highlighting Status Changes in Patient Information: As noted above, excessive redundancy arising from 'copying and pasting' unchanged patient data can make it difficult to find information of interest within EHR documents, promote the propagation of data inconsistencies (15), and make the process of reviewing these documents error-prone and time consuming. However, redundant information can contribute to creating a contextual framework of clinical scenarios represented by narratives within the EHR. Therefore, to minimize the difficulty in navigation associated with duplication of clinical information and to leverage the contextual benefits of access to patient information, we recommend the implementation of methods to distinguish the most recent changes in patient information within the EHR clinical document as compared to details provided during a previous clinician-patient encounter. One of these methods involves highlighting these changes such that inductive cues are provided to aid clinicians in tracking and interpreting changes in the patient's healthcare status over time. Further research in natural language processing (NLP) may be necessary to develop applications that identify these changes and possibly extract them for effective disease risk and patient outcome assessment.

Glossary or Infolinks to Specialized Terms: Due to the continuum in clinical expertise and distinct nomenclature in several clinical specialties, demand for clinical decision support towards improved clinical expertise development may require ready access to tools that can aid the interpretation of terms and abbreviations commonly encountered while synthesizing documentations of patient care specific to certain specialties (28). Therefore, we recommend the development of customizable electronic glossaries of specialty-biased terms and abbreviations that can be edited by local and/or national clinical specialty organizations. Implementation of text-based infolinks to these glossaries within the EHR clinical document user can facilitate interpretation and synthesis of specialized terms at the point of care.

Limitations in this study include our sampling of clinicians with expertise at the intern level only, which meant we did not explore the potential influence of differences in clinical expertise and specialties on cognitive processes employed in synthesizing EHR clinical documents. Since only medical interns at the University of Minnesota participated in this study, our findings may not adequately reflect the cognitive processes or barriers experienced by other inter-disciplinary healthcare providers (e.g. nurses, pharmacists) and interns in other institutions as they routinely utilize EHR documents in caring for patients. Also, verbal protocols obtained while the interns synthesized electronic clinical text during the TA experiments were not controlled for quantity of speech and the possibility of additional cognitive processes directly related to 'speaking one's thoughts' during task performance. Finally, because the research was conducted in a simulated ambulatory setting using hypothetical clinical scenarios, TA experiments were void of any workflow interruptions and direct clinician-patient interaction (e.g. during physical examination) that are typical in realistic clinical settings. Therefore, the results of this study will need validation in the "in situ" clinical environment and among other groups of providers.

2.6 Conclusion

A scientific approach towards improving clinicians' synthesis of text-based EHR clinical documents during patient care requires studying clinicians' cognitive processes while performing routine clinical tasks using these documents. This work supports and informs the design of future EHR clinical document user interfaces. Qualitative methodologies were effective at revealing the cognitive processes and barriers associated with EHR document synthesis and helped to highlight how these processes can inform the design of EHR clinical document user interfaces. Given the limitations in our study, directions for future research include the analysis of cognitive processes associated with the synthesis of EHR clinical documents by physicians and other healthcare providers in various specialties and at different levels of clinical expertise. Research findings can also be validated based on ethnographic analysis of healthcare providers' cognitive processes employed in synthesizing EHR clinical documents within realistic patient care settings.

CHAPTER 3

EFFECTS OF TIME CONSTRAINTS ON CLINICIAN-COMPUTER INTERACTION: A STUDY ON INFORMATION SYNTHESIS FROM EHR CLINICAL NOTES

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Background: *Time is a measurable resource that remains critical to the quality of services provided in clinical practice. There is limited insight into the effects of time restrictions on clinicians' cognitive processes while providing ambulatory care in an EHR-driven environment.*

Objective and Methods: *To understand the impact of time constraints on clinicians' synthesis of text-based EHR clinical notes, we conducted a study based on a cognitive framework to analyze interns' thought processes as they accomplished a set of four preformed ambulatory care clinical scenarios with and without time restrictions in a controlled setting.*

Results: *Clinicians most often synthesized details relevant to patients' problems and treatment, regardless of whether or not the time available for task performance was restricted. In contrast to previous findings, subsequent information commonly* *synthesized by clinicians related to the chronology of clinical events for the unrestricted time observations, and investigative procedures for the restricted sessions. In addition, there was no significant difference in the mean number of omission errors and incorrect deductions when interns synthesized the EHR clinical notes with and without the time restriction (3.5 ± 0.6 vs 2.3 ± 0.5, p = 0.17).*

Conclusion: *Our results suggest that the incidence of errors during clinicians' synthesis of EHR clinical notes is not increased under the time restriction in this study possibly due to effective adjustments of information processing strategies learned from the usual time-constrained nature of patient visits. Further research is required to investigate the effects of similar time variations on cognitive processes employed by different clinician types as they synthesize EHR clinical notes within various patient care settings.*

3.1 Introduction

With the ongoing integration of EHR systems within mainstream patient care and healthcare operations, the mechanisms and solutions to challenges with clinician-computer interaction have emerged as fundamental areas of clinical informatics research. Recent studies have illustrated the importance of evaluating clinician efficiency with HIT towards successful individual and organizational adoption of HIT solutions (82-85). Accordingly, there has been significant emphasis on understanding cognitive demands imposed on clinicians as they interact with EHR systems to inform the design of future systems to effectively support clinician behavior and reduce their cognitive burden within the practice environment (26,52,83,86).

Although time pressures appear to compound clinicians' cognitive load and multitasking activities while providing care in the typically stressful emergency department (86), there is limited insight on the effects time restrictions can have on clinicians' cognitive processes while providing ambulatory care (primary care or internal medicine). As a follow-up to a study investigating cognitive processes involved in synthesizing electronic clinical documents (87), we conducted a set of similar analyses to understand how time constraints experienced by clinicians during out-patient care influence the cognitive processes they employ while synthesizing EHR clinical text notes.

3.2 Background

3.2.1 Impact of Time Limits in Ambulatory Care

There is evidence to support integrating preventive care, patient-centered services, and acute care needs in the ambulatory environment to decrease costs while optimizing healthcare quality and improve patient outcomes (88,89). However, time requirements for these essential services do not correspond with the average length of routine ambulatory consultation which, according to Konrad et al., were estimated at 6, 10 and 18 minutes in Germany, England and the US respectively(90,91). In Yarnall et al.'s study to determine the amount of time required for preventive services in primary care, excluding the time needed to review medical records and detect patient-specific needs, physicians required

7.4 hours per working day to adequately adhere to the US Preventive Services Task Force (USPSTF) guidelines (41). This is obviously more time than physicians can afford, considering their already significant working hours and all of the additional tasks and processes required for patient care, including creating the office visit note and ordering tests/medications. For these reasons, time restrictions are highly important and may have a significant impact upon the delivery of quality preventive and therapeutic services (72,91,92). While we hypothesize that the impact of time constraints is likely negative upon care, there is minimal evidence assessing this rigorously in practice.

In a set of experiments to evaluate the effects of time constraints on patient satisfaction and clinical content during out-patient consultations, Morrell et al. discovered that physicians who saw patients for approx 6 minutes at 5 minute-intervals could not fully comprehend the clinical situation, had limited time for efficient documentation, and patients were generally dissatisfied with the consultations (93). Similarly, Tarn et al.'s observational study with ambulatory care visits revealed that physician communication to patients about new prescriptions was often incomplete, and efforts to improve communication should focus on both the quality of physician-patient discussions and trade-offs during time-restricted office visits (94).

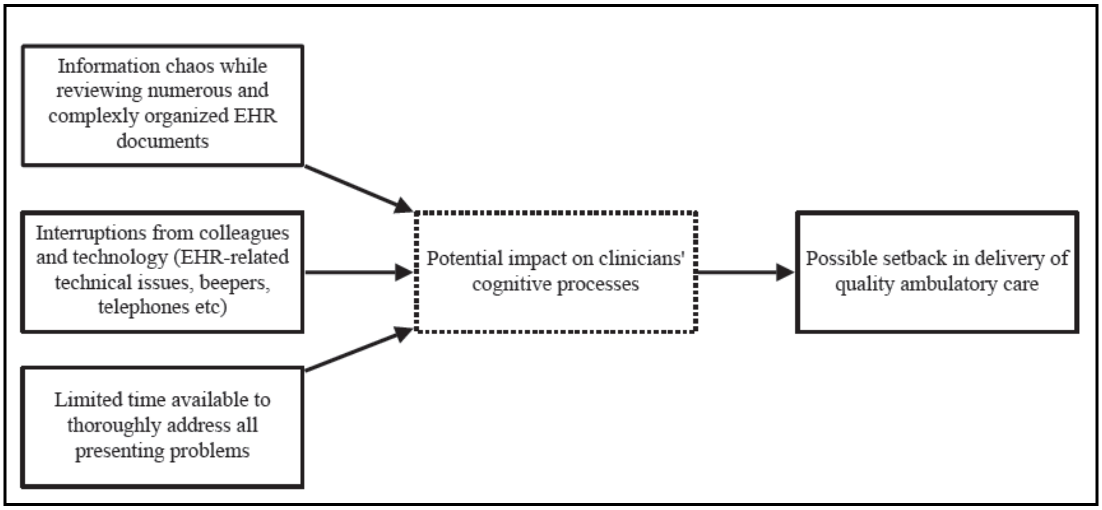

Figure 3.1: Potential Factors Influencing Clinicians’ Cognitive Processes in Ambulatory Care

More insight into the impact of time limits on clinical processes is necessary to recommend better strategies for improved clinician cognitive processes and provision of holistic ambulatory care in the setting of using an EHR system. Figure 3.1 outlines some factors that can potentially influence clinician cognitive processes employed while using EHR systems within ambulatory care settings.

3.2.2 EHR systems, Cognitive Overload and Time Pressures

According to a review on HIT return on investment by Menachemi and Brooks, implementing EHR systems within various healthcare settings has led to numerous benefits including improved patient safety for medication ordering and prescribing, improved coordination of care, and increased access to relevant health data (95). Despite providing better availability of a rich array of patient information, EHR systems can amplify the cognitive burden experienced by clinicians while providing care (96). Beasley et al. described information chaos (a phenomenon comprising information overload, underload, scatter, conflict and errors) as a negative effect of using EHR systems at the primary care level (Figure 1). Information chaos may potentially increase the physicians' mental workload, impair their understanding of task-related situations, and may hinder timely and accurate clinical decision-making (16).

Zhang et al. observed several clinician characteristics possibly mediating errors in patient care include attention switching, inadequate recall, reasoning errors and cognitive overload (97). Cognitive overload is said to arise when overwhelming quantities of information are combined with multitasking and interruptions (98,99). Interruptions due to colleagues requesting a clinician's attention or a malfunction in the EHR system are sometimes unavoidable and may reduce the clinician's ability to efficiently handle the cognitive burden of patient care (16). Investigators have also stated that cognitive overload when providing care can result in disruption of clinicians' 'control' over the clinical situation; such loss of control increases the likelihood of errors in patient management (25,96).

Apart from the cognitive load generally imposed by clinical information processing (26), time pressures associated with patient visits may also tax a clinician's cognitive capacity and require the clinician to adjust his/her information processing rate and strategy (100). In situations of high workload and patient volume, time constraints may promote specific clinician behavior such as indiscriminate copying and pasting of electronic patient information, thereby creating voluminous EHR notes with a large amount of redundant and extraneous information that may compromise accurate information synthesis downstream (101). Some studies also suggest that additional clinician time is required when documenting in EHR systems when compared to time documenting with paper records (9,102,137). Pizziferri et al., in contrast, found that physician time utilization remained unchanged despite EHR system use. This study also found that understanding physician time management related to EHR use may be crucial to the acceptance of this technology (103).

In a previous study we examined clinician's cognitive processes in synthesizing information from clinical documents in an EHR (87) using a think-aloud (TA) protocol. From that work we derived the pathway model in Figure 3. However we did not examine the impact that time constraints might have on these cognitive processes as a potential explanation for effects of time constraints cited above. In order to examine the previous cognitive pathway and related findings in the context of the typically time-constrained patient visit, this study applies similar experimental design and qualitative analysis technique within a simulated ambulatory setting as clinicians performed a set of preformed clinical scenarios under timed and untimed conditions.

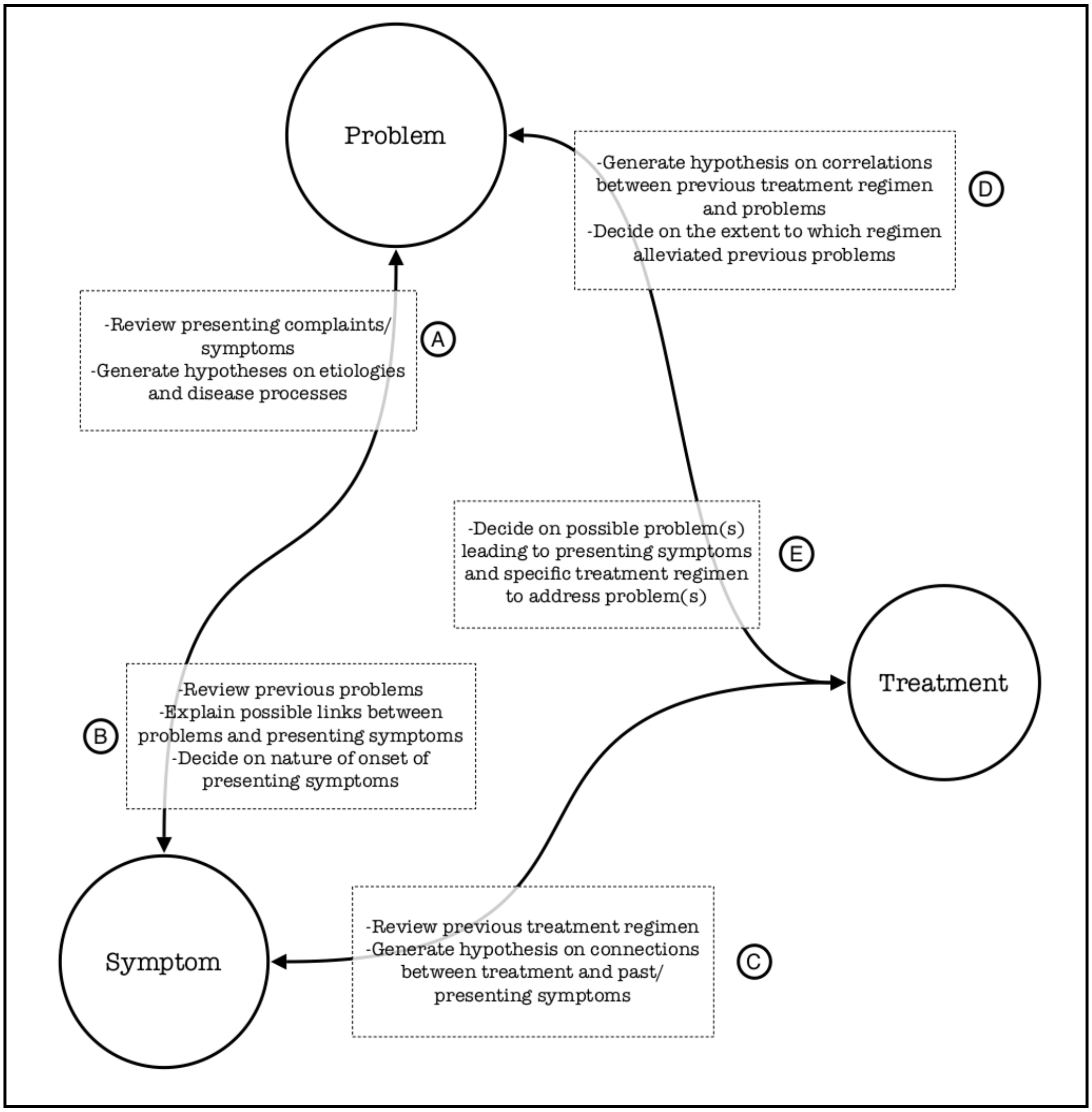

Figure 3.2: Common Cognitive Pathway of Interns Synthesizing EHR Clinical Documents (87)

3.3 Methods

We used a mixed methods approach in analyzing clinicians' thought processes as they accomplished routine ambulatory care clinical tasks with and without time restrictions to understand the impact of time constraints on clinicians' review of text-based EHR clinical notes. The TA protocol was used as the primary data collection method since it provides data on individuals' thoughts during task performance in the form of verbal protocols (30,50,51,104). Analysis of the study transcripts was informed by similar procedures utilized in a previous study using a three-step protocol analysis in investigating the cognitive processes of interns as they synthesized EHR clinical notes with and without time restrictions. To determine interrater reliability during the protocol analysis, another investigator (KM) experienced in qualitative research analyzed a subset (10%) of the study transcripts. There was very good agreement between the two investigators (mean agreement = 98.5%, $\kappa = 0.97$). Potential discrepancies between the investigators' coding procedures were addressed and examined for overlaps.
Based on results from the protocol analysis, we compared the cognitive pathway from the earlier study to two similar but distinct pathways exemplifying the synthesis of EHR clinical documents while clinicians provided ambulatory care under timed and untimed conditions.

Using statistical procedure appropriate for small study samples (Student's t-test) (105), we analyzed the differences in average numbers of concepts and assertions representing the interns' information processing and the average number of errors during their synthesis of the EHR notes with and without a time restriction. For the t-test, we used an α-level of 0.05. Approval for this study was obtained from the University of Minnesota Institutional Review Board (Study Number: 1012E93487). QSR NVIVO® 9 was used to analyze transcripts of the clinicians verbalizations obtained during the TA observations.

3.3.1 Study Sample

We selected a convenience sample of physicians at the University of Minnesota Medical Center to participate in the study. To minimize variability in clinical expertise and allow for a considerable range of technical expertise in the study sample, we recruited only interns familiar with two to four vendor-based EHR systems currently implemented in various healthcare centers nationwide.

3.3.2 Experimental Design

Patient records were sampled from a large cohort of patients diagnosed with diabetes and other comorbidities (e.g. hypertension and dyslipidemia) at the University of Minnesota affiliated Fairview Health Services. Based on the study objective, outpatient progress notes over a one-year period within each patient record were selected for the TA experiments, resulting in eight or nine office visit notes per record. There were no in-patient notes included in these records.

In line with simulations utilized in TA protocols (50,106), we selected four patient records and corresponding clinical scenarios from a set of nine records used in the previous study. The records were selected after excluding atypical records (e.g. that had missed appointments) and those with average scores of ≤ 5 assigned on a 10-point scale (1- lowest, 10-highest) by physician subjects for each of two measures; 1) completeness of the clinical information within the record, and 2) the degree to which the record assisted with performing the assigned clinical scenario. Each clinical scenario required the physician to admit a hypothetical patient, write a specialist referral or summarize a patient record by synthesizing narratives in EHR clinical notes. To eliminate potential bias due to recall of the selected records and clinical scenarios, no physician subject from the previous research was recruited for this study.

Physicians participating in this study were instructed to verbalize their thought processes (‘think-aloud’) as they synthesized the selected patient records within a prototype EHR user interface and accomplished related clinical tasks under timed and untimed conditions in a simulated ambulatory care setting. Physician participants in this study were presented with the clinical scenarios and associated tasks to complete using a prototype EHR user interface. They were instructed to think aloud as they worked their way through clinical notes within the patient records. During a set of time-restricted observations, the countdown clock began when clinicians logged into the EHR user interface and ended either when the allocated time period elapsed or when the clinicians indicated they had completed the task, whichever came earlier. In the equivalent unrestricted observations, clinicians were instructed to take as much time as needed to review the patient record s and complete the assigned clinical tasks. The end of an observation under this condition was the point at which clinicians signified that an associated clinical task was accomplished.

To determine an appropriate time restriction (i.e. time between when clinicians log into the EHR user interface to when they accomplish the clinical scenario), we examined the time to task completion for each scenario based on the previous study; average duration of task accomplishment for each scenario was estimated at 13, 14, 15 and 20 minutes. To validate our preference for a time limit in the study experiments, we reviewed relevant literature (44,107,108) and gathered clinician experts' perspectives on the typical duration of routine out-patient consultations. At the end of this process, we decided on *12 minute* duration as the time limit for the TA observations that would be compared to a similar set carried out without time restrictions. We concluded that this time period would be adequate to simulate realistic routine ambulatory care visits such that it provides ample time to accomplish necessary care processes for a 'virtual' patient excluding physical examination and patient counseling.

3.4 Results

Four female and four male interns between 25 and 31 years were observed as they simultaneously thought aloud, synthesized information from patient records, and accomplished clinical tasks outlined in the corresponding clinical scenarios. Each intern first performed one clinical scenario without being timed and then another under the 12-minute time restriction. The range of time to task completion during the untimed and timed observations was 9 – 32 mins and 8 – 12 mins respectively (Table 3.1). The TA protocol was designed such that each intern had only one exposure to a clinical scenario so as to emphasize information processing resulting from direct synthesis rather than recall.

Table 3.1 Duration of Timed and Untimed Clinical Scenarios

Clinician ID	**Scenario 1 (mins)**	**Scenario 2 (mins)**	**Scenario 3 (mins)**	**Scenario 4 (mins)**
1	U (9)	T (12)		
2	T (12)	U (14)		
3			U (22)	T (12)
4			T (8)	U (23)
5	U (32)	T (12)		
6	T (12)	U (31)		
7			U (21)	T (12)
8			T (12)	U (21)

Key
U = Untimed
T = Timed

With the clinical scenarios, interns were required to create new clinical notes (referrals, summaries or admission notes) based on information synthesized from the patient records; these were evaluated and found to be analogous in overall organization and clinically relevant details.

3.4.1 Protocol Analysis

3.4.1.1 Referral Phrase Analysis

During the referral phrase analysis (RPA) (109), nouns and noun phrases in the study transcripts were analyzed to identify concepts that reflected the intern's reasoning and the information being processed at a particular instance. These concepts constituted an ontology representing the interns' information processing and synthesis of patient information relevant to the clinical scenarios (81).

The RPA was carried out iteratively until all concepts in the transcribed data were defined and coded. Interns' verbalizations were coded under nine RPA concepts defined in the previous study to represent their cognitive activities and information retrieval as they performed routine clinical tasks with and without time restrictions. The concepts include *Problem*, *Treatment*, *Symptom*, *Sign*, *Test*, *Time*, *Value*, *Action* and *Format* (Table 3.2). We identified that the highest frequencies of information synthesized by interns related to concepts of *Problem* (such as past and current diagnoses, family and social history, and allergies) and *Treatment* when they review the clinical documents under both timed and untimed conditions. These predominant concepts were also the most frequent concepts that informed the design of a common cognitive pathway in the earlier study. Although references to the *Symptom* concept were as frequent as the *Problem* and *Treatment* concepts in the prior study, this study showed that the next most occurring concept indicating the interns' information processing patterns was *Time* for the untimed TA observations, and *Test* for the timed equivalents (Table 3.3).

To examine the impact of time restrictions we examined the mean number of references coded under each concept for the timed and untimed clinical scenarios. During the untimed observations, interns synthesized relatively more information under the *Problem* concept (40.8 ± 3.0) compared to when they were timed (23.5 ± 4.3) (p = 0.02). Similarly, interns assessed the relevance of clinical text (*Value*) in the patient records much more for the clinical scenarios without time constraints (13.0 ± 1.8 vs 3.5 ± 1.2, p = 0.004). The average number of references under the *Time* (20.8 ± 5.9 vs 5.3 ± 0.8, p = 0.08), *Symptom* (16.3 ± 3.7 vs 7.0 ± 1.5, p = 0.08), and *Format* (3.0 ± 0.8 vs 1.0 ± 0.4, p = 0.07) concepts exhibited a similar trend favoring the untimed condition but were not significant at the established $\alpha = 0.05$ level. Likewise, differences in the average numbers of the other concepts (*Treatment*, *Test*, *Sign* and *Action*) under timed and untimed conditions were not statistically significant (Table 3.3)

Table 3.2 Referral Phrase Analysis

Concept	Definition	Example from Transcripts
Problem	past and current clinically relevant problems	"So he's got *COPD, high blood pressure and diabetes and knee problems*"
Treatment	therapeutic and preventative procedures	"Active *medication*; he's on things for pain- *NSAIDS and vicodin*"
Symptom	subjective clinical information reflecting health status	"No *symptoms* at the time- a little bit of a *cough*, and I think some *pain*"
Test	investigative procedures to check clinical status	"So the *HDL* level's a little low at 31; *cholesterol* is fine"
Time	indicates a chronological reference	"Triglycerides have come down *since previous visit*"
Action	indicates performance of an activity (mainly navigating)	"I'm just going to *page through* real quick here to try to figure out the first time that left knee pain popped up"
Sign	objective clinical information reflecting clinical status	"Here's the *exam- vitals are good; lungs are clear*"
Value	assessment of clinical information's relevance	"And long list of prescriptions- I'm *not really concerned with that* at this point in time"
Format	organization and presentation of clinical information	"I don't know- these are like very *cumbersome notes*"

Table 3.3 Quantitative Analysis of Referral Phrase Concepts

Concept	Untimed (N = 4) Mean ± SE (Total)	Timed (N = 4) Mean ± SE (Total)	P-value
Problem	40.8 ± 3.0 (163)	23.5 ± 4.3 (94)	0.02*
Treatment	25.3 ± 6.0 (101)	15.8 ± 1.1 (63)	0.21
Symptom	16.3 ± 3.7 (65)	7.0 ± 1.5 (28)	0.08
Time	20.8 ± 5.9 (83)	5.3 ± 0.8 (21)	0.08
Test	18.0 ± 2.1 (72)	11.3 ± 3.2 (45)	0.13
Action	16.8 ± 6.2 (67)	7.0 ± 1.0 (28)	0.21
Sign	12.8 ± 4.6 (51)	7.8 ± 1.9 (31)	0.38
Value	13.0 ± 1.8 (52)	3.5 ± 1.2 (14)	0.004*
Format	3.0 ± 0.8 (12)	1.0 ± 0.4 (4)	0.07

∗Statistically significant (α level = 0.05)

3.4.1.2 Assertional Analysis

Following the RPA, we analyzed the study transcripts to determine the nature and validity of relationships established between nouns and noun phrases verbalized during the TA observations (Table 3.4). Similar to findings in the earlier study, the predominant relationships identified during the assertional analysis (AA) representing clinical reasoning associated with interns' synthesis of EHR document during task performance were those denoting meaning (implicative) and significance (significative). Frequencies of the interns' assertion revealed mostly *Significative* and *Implicative* relationships between RPA concepts under timed and untimed conditions. However, there were relatively more *Significative* relationships when there was no time restriction (33.0 ± 2.0 vs 21.5 ± 2.7, p = 0.01). Average values for the remaining two categories (*Implicative* and *Causal*) were not statistically different (Table 3.5).

Table 3.4 Assertional Analysis

Assertion	Definition	Example from Transcripts
Implicative	relationship of meaning	"Let's see how his sugars are; they're not very especially well controlled"
Significative	relationship of significance	"I'll probably check his BMP and electrolytes"
Causal	relationship of etiology	"And he also suffers from impotence likely secondary to his diabetes"

Table 3.5 Quantitative Analysis of Assertional Themes

Assertion	Untimed (N = 4) Mean ± SE (Total)	Timed (N = 4) Mean ± SE (Total)	P-value
Implicative	28.3 ± 4.3 (113)	18.8 ± 4.2 (75)	0.16
Significative	33.0 ± 2.0 (132)	21.5 ± 2.7 (86)	0.01*
Causal	8.5 ± 2.7 (34)	4.8 ± 0.9 (19)	0.27

∗Statistically significant (α level = 0.05)

3.4.1.3. Script Analysis

The final step in the protocol analysis was a script analysis (SA) which helped unravel the overall configuration of interns' reasoning patterns and clinical judgment as they performed the clinical scenarios (78). For the SA, all coded statements from the RPA and AA were examined more closely to understand the predominant cognitive strategies employed by the interns in accomplishing the clinical scenarios (50). Similar to the operators note in the previous study, we identified the interns' cognitive activities represented by their thought processes as a combination of these operators- *Review, Deduce, Decide, and Assume.* In addition, we included another operator, *Error*, to categorize statements that reflected incorrect inferences and/or failure to retrieve available information during synthesis of the EHR notes (Table 3.6).

From results in table 3.7, average numbers of references under *Assume* were significantly more when interns accomplished clinical scenarios without time restrictions (7.0 ± 1.2 vs 2.8 ± 0.5, p = 0.03). References for *Deduce* were also significantly greater for the untimed observations when compared to the average value for the timed sessions (38.0 ± 4.3 vs 21.3 ± 5.2, p = 0.05). However, the difference in the average number of errors during the timed and untimed observations was not statistically significant (3.5 ± 0.6 vs 2.3 ± 0.5, p = 0.17).

Table 3.6 Script Analysis

Operator	Definition	Example from Transcripts
Review	attentive consideration of patient details usually following a search	"I see the past left knee MRI showed meniscial fraying and cartilage thinning"
Deduce	make inferences based on evidence and clinical knowledge	"Especially if it gets worse with activity- even more suggestive of possibly peripheral vascular disease"
Assume	relates to making an assumption	"Unclear if patient still has pacer; maybe it was a temporary issue"
Decide	choose a line of action to provide care for the patient	"We'll draw a CBC- see what his white count looks like"
Error	Inaccurate inferences or inability to identify relevant patient information	"Ask if there is any history of gout which I didn't see, but I didn't read his podiatry notes" (Note: *There was a history of gout in the patient record*)

Table 3.7 Quantitative Analysis of Script Analysis Operators

Operator	Untimed (N = 4) Total (Mean ± SE)	Timed (N = 4) Total (Mean ± SE)	P-value
Review	38 (9.5 ± 3.4)	32 (8.0 ± 2.5)	0.74
Deduce	152(38.0 ± 4.3)	85 (21.3 ± 5.2)	0.05*
Presume	28 (7.0 ± 1.2)	11 (2.8 ± 0.5)	0.03*
Decide	43 (10.8 ± 1.0)	40 (10.0 ± 4.1)	0.87
Error	14 (3.5 ± 0.6)	9 (2.3 ± 0.5)	0.17

∗Statistically significant (α level = 0.05)

3.4.2 Cognitive Pathways with and without Time Restriction

Based on the predominant themes from the protocol analysis, we constructed common cognitive pathways (similar to that with the previous study) to represent the synthesis of EHR clinical notes by interns with and without the introduction of time restrictions. .

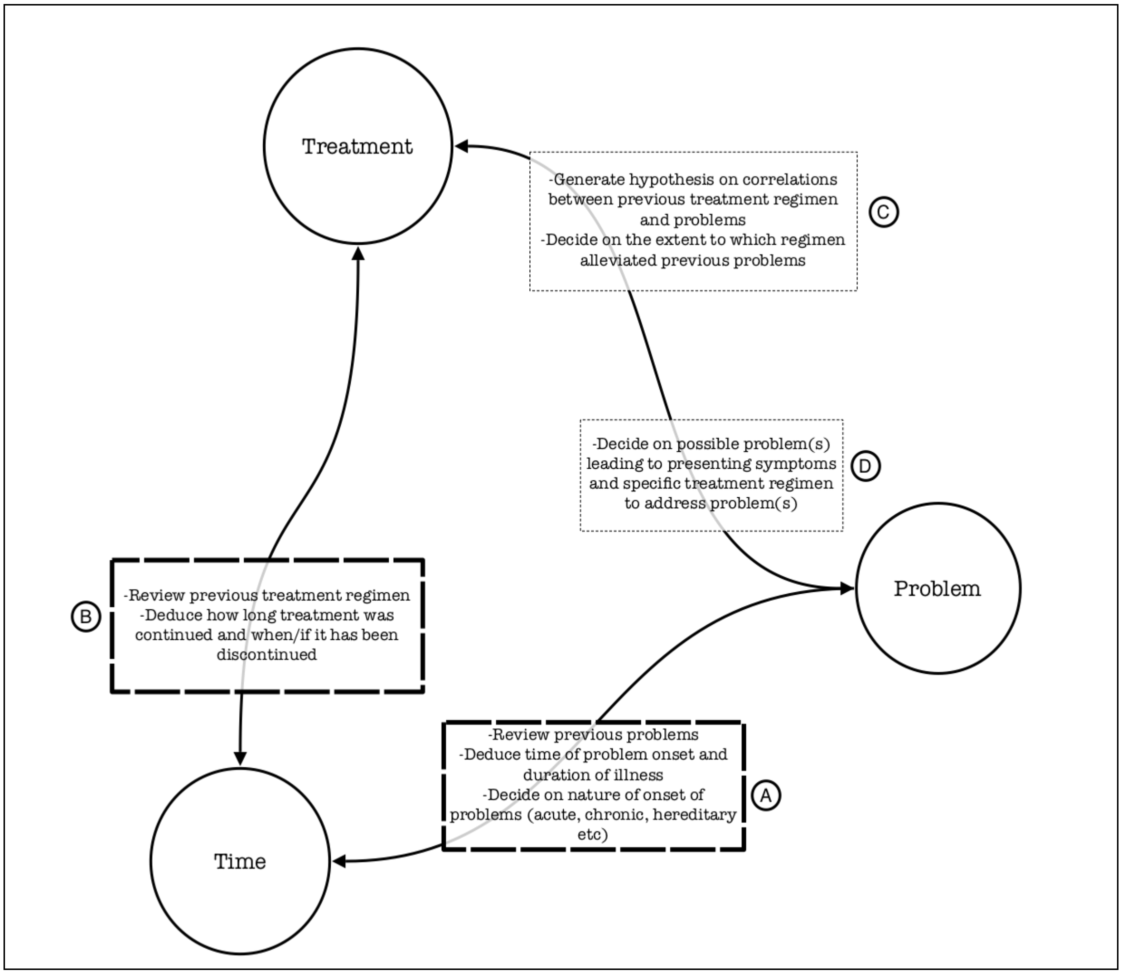

Figure 3.3 Common Cognitive Pathway for Untimed Observations

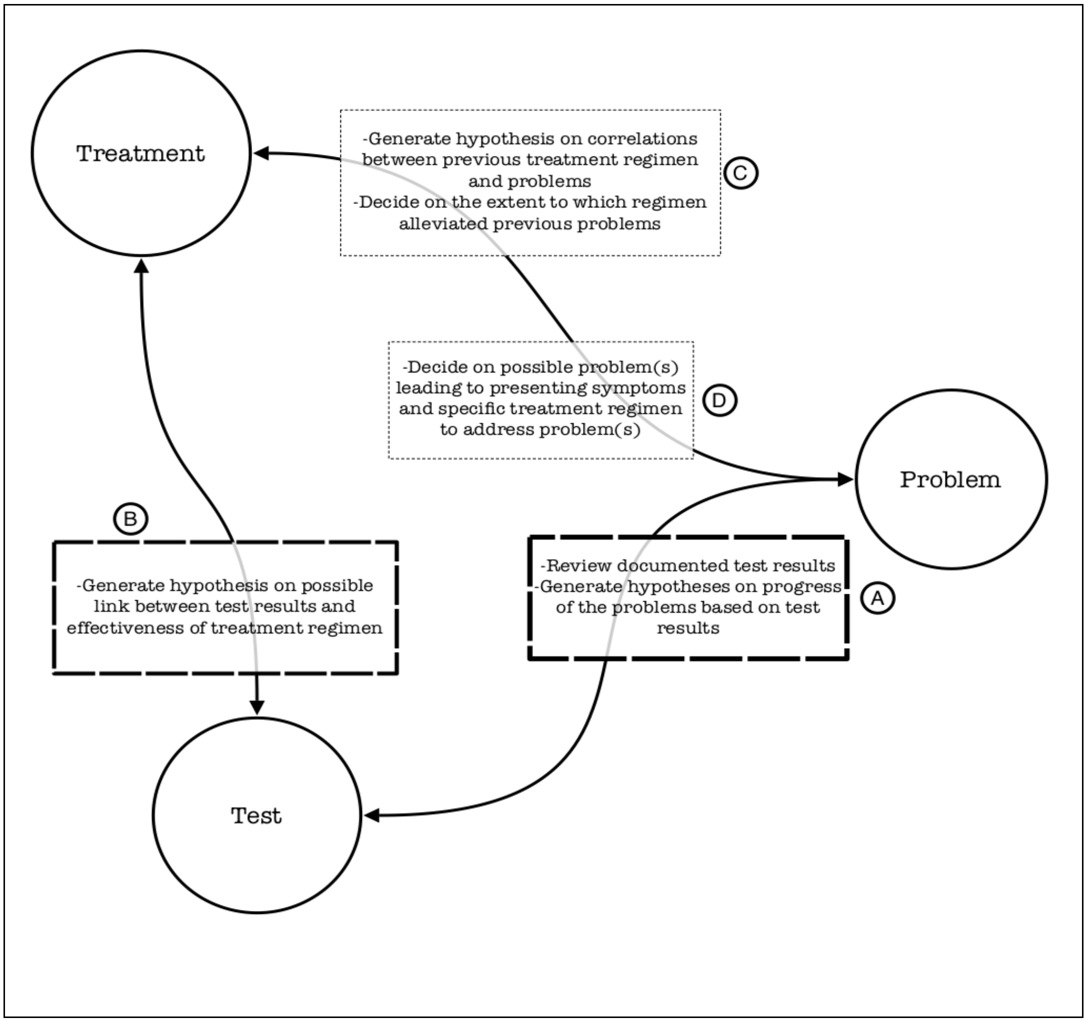

Figure 3.4 Common Cognitive Pathway for Timed Observations

As outline in figure 3.3, without the time restriction, the interns' essentially focused on synthesizing time-related clinical details to determine time of illness onset and duration of existing problems (A), and the length of time for which interventions/treatment were administered (B). In contrast, during the timed observations, interns' synthesized test results to determine the progress of patient problems (A) and attempted to establish links between test results and the effectiveness of interventions (B) (Figure 3.4). Cognitive activities common to all three pathways are interns' information processing to establish possible connections between problems and prescribed treatment, and their assessment of the degree to which treatment regimens have alleviated existing patient problems (C and D) (Figures 3.2, 3.3 and 3.4).

3.5 Discussion

Time is a measurable resource that remains critical to the quality of services provided in clinical practice (110,111). The current adoption of EHR systems in ambulatory care and demands to provide comprehensive and quality healthcare often require that clinicians review large amounts of EHR clinical text documents within the typically time-constrained clinical encounter (16,44,85). The cognitive challenges with consuming complex and often redundant electronic patient information has been the focus of research in cognitive science and human-computer interaction over the last few years (15,20,66,96,112). However, in our opinion, there has been little emphasis on how time constraints in ambulatory care influence the cognitive processes of clinicians as they interact with text documents in EHR systems.

Based on our previous study investigating cognitive processes of clinicians associated with their consumption of EHR clinical notes, the focus of this work was to explore the possible impact of time constraints on interns' cognitive processes when they accomplished clinical tasks during ambulatory care. Our results corroborated findings in the earlier study suggesting that interns most often synthesized details relevant to

Problem and *Treatment* concepts, regardless of the time available for task performance. However, in contrast to the relatively large number of references to *Symptom* in the previous study, instances of the concepts of *Time* were the next most frequent during the untimed observations while the instances of the *Test* concept were similarly frequent during the timed observations.

Variations in information processing patterns observed in the three practice situations may be possibly linked to instructions on time availability provided to the interns prior to participating in the timed and untimed observations. The interns' consciousness of time restrictions, or the absence thereof, may have resulted in significant adjustments to their information processing strategies while synthesizing the EHR clinical notes- evidenced by their emphases on different categories of clinical details (*Symptom*, *Time* and *Test*) under the different practice situations. These findings offer potential considerations for future designs of EHR clinical note user interfaces as the influence of time constraints on clinicians' cognitive strategies during patient care may need to be adequately addressed by current EHR systems. To promote better clinician satisfaction with these systems, developing solutions to optimize the display of particular details within EHR clinical narratives may be helpful. Furthermore, clinicians' demand for information on patients' problems and treatment observed under all the practice conditions may present a rationale for the implementation of tools within EHR systems to enable retrieval of these classes of information when clinicians are under time pressure.

Given that the average duration of the untimed observations was about twice that of the timed observations, we expected that interns would have relatively more references under the themes in the protocol analysis of data from the untimed experiments, since they could synthesize more clinical information in the additional time available. Although the frequencies of the concepts, assertions and operators under both conditions supported our logical reasoning, statistical analysis showed only significantly more references during the untimed sessions for *Problem* and *Value* concepts, *Significative* assertions, and the *Assume* operator. Based on evidence that physicians usually attempt to 'down-size' the quantity of information they need to review or simplify their information processing technique when they take on complex clinical tasks under time restrictions (53), we expected that interns would be inclined to more ongoing and brisk assessments of the relevance of patient information within the EHR clinical notes when they were faced with time pressures. However, our findings contradict this notion as the interns evaluated the importance of textual data relative to the designated clinical scenarios much more when there was no time restriction. The prevalence of the *Value* concept during the untimed observations also correlates with relatively more *Significative* assertions (relationship of significance) compared to the timed equivalents. More research may be necessary to better understand the rationale behind clinicians' evaluation of details within EHR clinical notes when time pressures eliminated.

The prevalence of assumptions (*Assume*) and deductions (*Deduce*) during the untimed observations may indicate that the interns' tried to make scientific connections from the larger amount of synthesized patient information when there was more time available. However, the synthesis of less information during the timed observations did not translate to a significant difference in the average numbers of errors when they reviewed the EHR clinical notes to accomplish the clinical scenarios. This phenomenon may be due to the general tendency of clinicians, by virtue of their training and clinical experience, to become accustomed to effectively streamlining patient information processing in the context of limited time resources (113). Therefore the ‘quality’ of the interns’ EHR clinical note synthesis may not necessarily fluctuate with the time restrictions employed in this study. However, future studies will be needed to validate this observation by repeatedly altering the time duration and possibly to validate in another practice setting to determine the precise impact of wider time variations on clinicians’ cognitive processes while synthesizing EHR clinical notes.

Some characteristics of the study design may present limitations. Sampling of only medical interns for our group of physicians at a single center may not allow the generalization of study results beyond interns or to physicians at other health centers. These findings similarly may not translate to more experienced physicians and specialists, and other non-physician clinicians within the healthcare system. Also, verbal protocols obtained while the interns synthesized electronic clinical text during the TA experiments were not controlled for quantity of speech and the possibility of additional cognitive processes directly related to ‘speaking one’s thoughts’ during task performance. Furthermore, our study was conducted in a simulated ambulatory setting and validation of these results in a naturalistic setting in the context of interruptions and multitasking will be needed.

3.6 Conclusion

Overall, study findings reveal that time restrictions on clinicians' synthesis of EHR clinical notes resulted in the retrieval of less amounts of available patient information. Based on the cognitive models developed from the study data, there was a considerable shift of clinicians' information processing strategies from retrieving details on the chronology of clinical events (*Time*) during untimed observations to reviewing laboratory results (*Test*) during the timed versions. Despite the relatively incomplete information synthesis under timed conditions, clinicians' review of EHR clinical notes was not associated with significantly more errors of omission or incorrect deductions compared to the untimed conditions. We suggest that the likelihood of errors during synthesis of EHR clinical notes was not increased with time restrictions possibly due to physicians being accustomed to making effective adjustments in information processing strategies based on the usually time-constrained patient visit.

Given the study limitations, further research is required to investigate the impact of similar time variations on cognitive processes associated with electronic clinical note synthesis by different clinician types and within various patient care environments.

3.7 Human Subjects Protection

The study was performed in compliance with the World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects. Prior to commencement of the study, all selected patient records were de-identified using the safe-harbor method. Approval for this study was obtained from the University of Minnesota Institutional Review Board (Study Number: 1012E93487).

3.8 Conflicts of Interest

The authors declare that they have no conflicts of interest in the research.

CHAPTER 4

IMPACT OF A PROTOTYPE VISUALIZATION TOOL FOR NEW INFORMATION IN EHR CLINICAL DOCUMENTS

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Background: *The synthesis of EHR clinical documents by clinicians may be difficult, time-consuming and error-prone due to the complex organization of narratives, excessive redundancy within documents, and, at times, inadvertent proliferation of data inconsistencies. Development of user-centric EHR systems requires research into visualization techniques that can optimize information synthesis at the point of care.*

Objective: *To evaluate the effect of a prototype visualization tool for clinically relevant new information on clinicians' synthesis of EHR clinical documents and to understand how the tool may support future designs of clinical document user interfaces.*

Methods*: A mixed methods approach to analyze the impact of the visualization tool was used with a sample of eight medical interns as they synthesized EHR clinical documents to accomplish four pre-formed clinical scenarios using a think-aloud protocol.*

Results: *Retrieval of available patient information (2.3 ± 1.1 vs 6.8 ± 3.4, $p = 0.02$) and accurate inferences (2.3 ± 1.1 vs 1.3 ± 0.6, $p = 0.03$) were significantly improved with the new information visualization tool compared to accomplishing scenarios without the tool.*

Despite the non-significant difference in total times to task completion (43 ± 1mins vs 36 ± 5 mins, p = 0.26) we observed shorter times for two scenarios with the visualization tool, suggesting that the time-saving benefits may be more evident with certain clinical processes. Other effects of the tool include enhanced consumption of time-related changes in clinical status, faster navigation between patient details, and increased efforts towards methodical synthesis of clinical documents.

Conclusion: *Our study provides evidence that new information visualization in clinical documents may improve synthesis of patient information by reducing incorrect deductions and missing relevant data while reviewing EHR clinical documents. Our findings provide groundwork towards a more user-centric display of EHR clinical documents using advanced visualization applications.*

Keywords: *Electronic Health Records, Data visualization, Interfaces and Usability*

4.1 Introduction

Current efforts in the U.S. healthcare towards increasing the adoption of HIT focus on improving access to patient data and clinical knowledge within the healthcare environment, with the goals of improving healthcare delivery, quality, and safety (9). Although EHR systems are recognized HIT solutions that support computerized documentation, these systems still contain visual components that replicate data presentation in paper-based media, which may not be optimal for clinician users. As such, some of the similar difficulties experienced by clinicians in navigating, retrieving, and synthesizing paper-based patient records remain unsolved with current EHR systems (114).

Clinicians typically create and review text-based EHR documents (e.g. progress notes and discharge summaries) in the process of patient care. These documents assist clinicians in constructing a contextual clinical understanding of a particular patient, serve as a medico-legal document of patient care, and communicate clinical reasoning, medical phenomena, and historical information (19). Current EHR systems possess limited user interface functionalities designed to augment navigation and synthesis of text-based documents (114). This represents an important opportunity to potentially provide more efficient and innovative note visualization ultimately aimed at improving patient care.

The objective of this study is to evaluate the effects of a new information visualization tool for clinical documents within a prototype EHR system.

4.2 Background

4.2.1 Medical Errors and EHR Clinical Document Synthesis

Recent studies on HIT adoption and computerized physician documentation outline potential benefits of EHR systems which include increased availability of patient data, access to evidence-based guidelines, and reduction of medical errors (35,85,115). Complex organization and varying granularity of details in EHR clinical documents often make clinicians' search for specific patient information haphazard and difficult (116).

While studies with paper-based health records have demonstrated that clinicians use clues such as individual penmanship of colleagues to identify relevant data in paper documents, electronic documents lack these helpful features, and identifying key pieces of information within electronic documents can be challenging (61). Additionally, poor organization of EHR clinical documents may contribute and perpetuate this challenge, as clinicians may have reduced motivation to thoroughly review 'visually unattractive' narratives, thus resulting in an increased likelihood to omit details pertinent to accurate diagnosis or reorder laboratory procedures and medications that can expose patients to considerable health risks (117).

During patient encounters, clinicians often review EHR clinical documents while multi-tasking, which might include communicating with patients or other clinicians and interruptions. Ash et al., in their study on unintended consequences of HIT, indicated that many EHR user interfaces are designed without careful consideration of the multi-tasking clinician and typically require undivided concentration to adequately synthesize relevant patient information (118). Similarly, in a study by Laxmisan et al., frequent workflow interruptions in the practice environment may contribute to increased cognitive load as clinicians synthesize EHR data (86). Also, brief periods of inattentiveness while reviewing these documents can lead to wrongful matching of dates and diagnostic or treatment details in close proximity (juxtaposition error) or abrupt loss of clinical history sequencing based on documentations from previous hospital visits (loss of overview) (118).

4.2.2 Redundancy in EHR Clinical Documents

When reviewing complex and lengthy patient records, clinicians typically read through clinical documents to abstract patient details and generate hypotheses related to the presenting clinical scenario (64). Investigators at Columbia University revealed that clinicians did not review about 20% of authored EHR documents, and the likelihood of reviewing these documents during patient care reduced with the age of the documents, difficulty in locating them within the EHR, and perceived irrelevance of documented patient information (62).

In composing a clinical document, clinicians often rewrite or 'copy and paste' unchanged text across subsequent documents to indicate that specific patient information remains true (119). Wrenn et al. found that duplicated patient information within sign-out and progress notes averaged 54% and 78% respectively, and that redundancy increased over the course of an inpatient hospitalization (15). In a study on outpatient clinic documents, Zhang et al. found that although redundancy generally increased with time, that ambulatory care records displayed a cyclical pattern of redundancy with dips in redundancy correlating with significant clinical care events (17). Although some 'copying and pasting' may have benign implications, significant redundancy in EHR clinical documents can introduce misleading information that may result in patient mismanagement (37). In addition, redundancy in EHR documents may complicate review and navigation through textual data, increase clinician cognitive load and negatively impact efficiency at putting together the ‘pieces of the patient’s puzzle’ (33,120).

4.2.3 Visualization of New Information within EHR Clinical Documents

Implementing visualization techniques to effectively distill new information from large quantities of clinical documents may support efforts to minimize erroneous data interpretations (96). Most textual data in the EHR are displayed using unsophisticated visual cues (e.g. spacing and paragraphing, lists and tables) which may not necessarily facilitate cognitive distinction of new and redundant information within clinical documents, although they support consumption of information in segments. (114,121). We hypothesize that introducing visual cues to support the discovery of relevant patient information may promote clinician efficiency while reviewing EHR documents and reduce the potential for omission errors.

4.3 Methods

We used a mixed methods approach to analyze the impact of the prototype visualization tool of new patient information on clinicians’ synthesis of EHR clinical documents while accomplishing a set of routine clinical tasks for a preformed clinical scenario on each patient.

4.3.1 Study Sample

According to sampling strategies used in human factors and usability research (77,122,123), we recruited a purposeful sample of interns at the University of Minnesota Medical Center while restricting study participation to the intern-level internal medicine physicians to minimize the confounding effect of clinical expertise. On the other hand, since each intern had a range of technical expertise and familiarity with EHR systems, while clinical expertise was more minimized, this variability remained.

4.3.2 A Prototype EHR Clinical Document User Interface

Using a spiral model for software development (Figure 4.1) and the EHR system user interface framework of the Veterans Affairs' computerized patient record system (VistA CPRS), we developed a prototype ambulatory EHR user interface with specific functionalities for clinical documents.

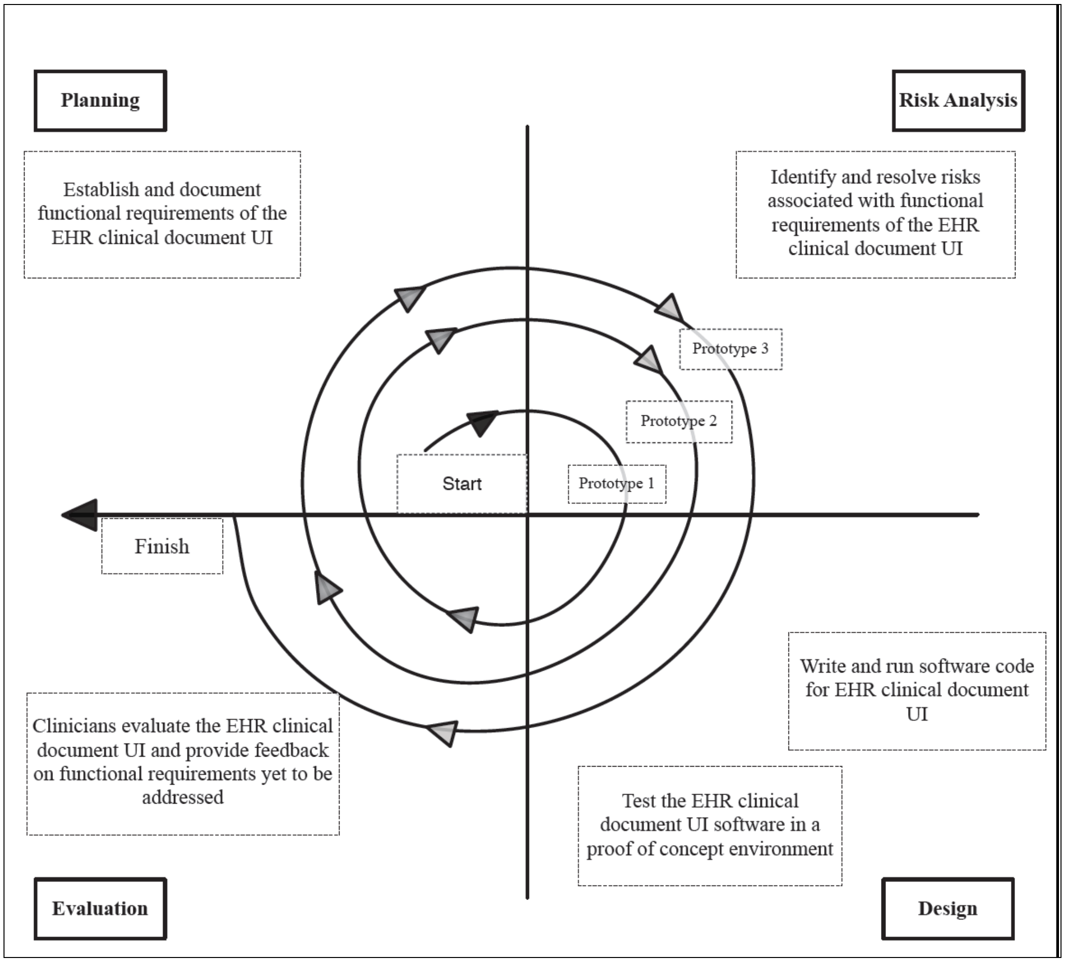

Figure 4.1: Spiral Model for Development of EHR Clinical Document User Interface (UI)

Evidence of the sizeable amounts of data redundancy in EHR clinical documents (15,120) and insights on interns' information processing patterns observed in our previous studies (15,87,120,124) provide a rationale for our implementation of a novel visualization tool to distinguish new (non-redundant) information from duplicated documentation of patient details. In addition, we replicated basic tools for reviewing and creating clinical documents in VistA CPRS e.g. the document viewer and a tab to create a new note. The main features of the prototype user interface, as shown in figure 4.2, include:

- *demographic panel*: located at the top of the user interface; provides basic patient information such as patient's names, date of birth, age and medical record number, healthcare provider's name and the out-patient clinic/specialty currently managing the patient
- *clinical document list*: contains clinical document metadata, including the names and specialties of authoring healthcare providers, dates of associated clinical encounters, and the clinical note type (e.g. office visit).
- *document viewer*: displays the selected clinical document in a read-only format and allows for extracts to be copied and pasted into a new document window.
- *review changes tab*: In line with evidence from an earlier study of clinicians' synthesis of EHR clinical documents involving processing of information on patients' symptoms, signs, problems, treatment, and tests, barriers to their information synthesis which include unnecessary data redundancy (87), and clinician investigators' (GM and OF) experiential knowledge on specific patient details (e.g. vital signs, treatment, diagnoses etc) that typically change across clinical notes over the course of healthcare utilization we implemented a visualization tool to highlight and improve clinicians' visual distinction of new and redundant textual data related to these information categories within a selected clinical note. Text was color-coded highlighting to identify clinically

relevant data *changed* in value or detail compared to the *preceding* clinical encounters. The highlighted text was colored coded into the following classes of information: *vitals*, *signs and symptoms*, *complaints*, *labs*, *problems*, and *plan*. For instance, as depicted in figure 4.2, users had the option while reviewing a particular clinical document, to have the 'review changes' tab activated for all types of information or particular types of information. If the user selected the option 'plan' only, the treatment plan was highlighted in brown within the clinical document.

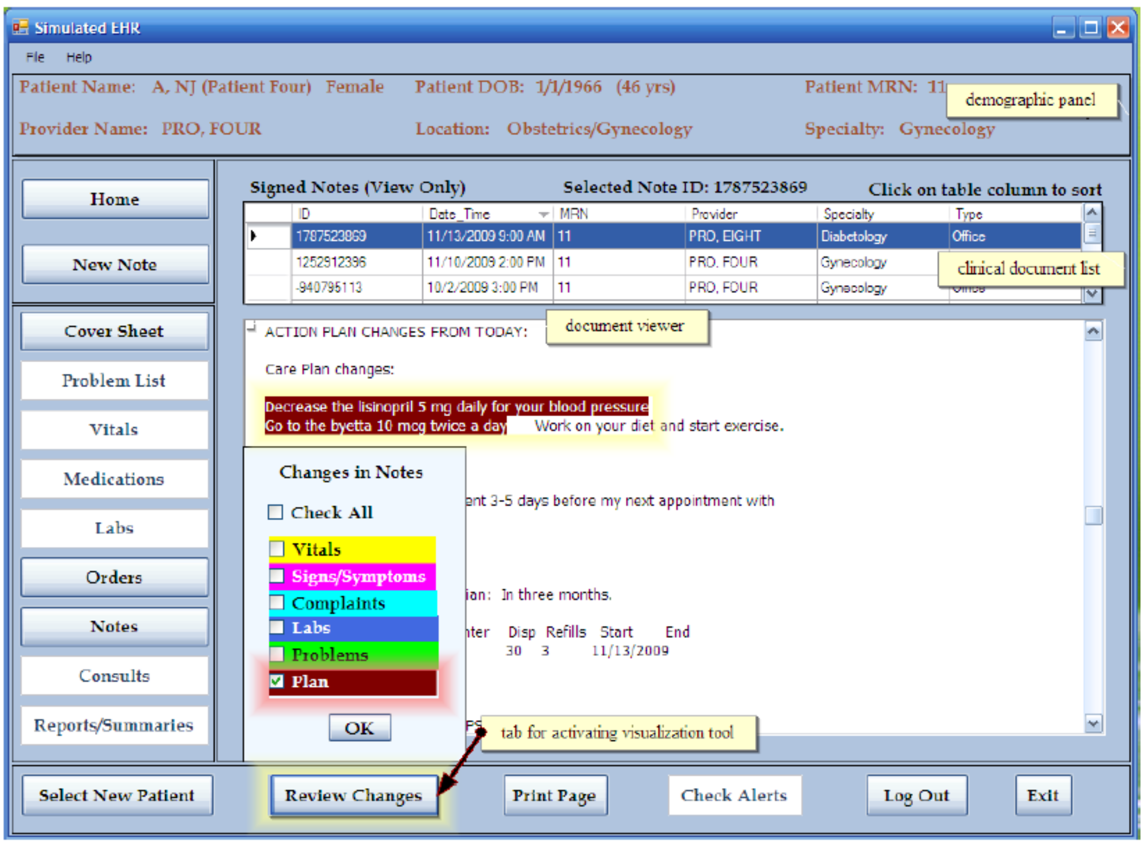

Figure 4.2: Main Features of the EHR Clinical Document User Interface

4.3.3 Experimental Design

We utilized a set of clinical scenarios from a previous study (124) to simulate problem-solving activities for a think-aloud (TA) protocol (50). The TA protocol is a qualitative research technique used in software usability evaluation to investigate users' cognitive behavior while performing assigned tasks to reveal reasoning patterns that indicate compatibility between software applications and users' cognitive activities (30,125). The tasks to be accomplished in these scenarios were routine clinical processes that required interns to synthesize patients' clinical documents (Table 4.1).

Table 4.1 Clinical Scenarios

Scenario ID	Summary	Task	Diagnosis
1	56 year old man presents with a 7-day history of pain and swelling in his left leg. The pain was gradual in onset and got worse whenever he walked up the stairs. He had a fever which got better after he took tylenol, except for some warmth in his lower extremity	Admit the patient	Cellulitis
2	53 year old man presents today after having a seizure 15 minutes before arrival. His daughter said he was acting confused and was sweating profusely prior to the seizure. His Temperature and BP taken at presentation were 98.2F and 110/75mmhg respectively.	Summarize the patient record	Hypoglycemia
3	77 year old woman was brought today after she told her partner that she vomited some blood in the earlier hours of the day. She says she's been feeling tired and breathless ever since the episodes of vomiting. She also complains of abdominal pain that is sometimes relieved on eating	Write a referral	Peptic ulcer disease
4	46 year old woman, presents with a 3-day history of mild confusion, high fever, chills, and cough with yellowish sputum. She also complained of worsening fatigue and loss of appetite. Her BP, Temperature and Respiratory rate taken at presentation were 100/70 mmHg, 101.8F and 32/min respectively	Admit the patient	Pneumonia

Interns were observed in a simulated ambulatory care setting as they thought aloud while summarizing specific patient records as part of an admission, consultation or referral. Each task required the intern to document relevant findings from existing clinical notes, his/her assessment of the patient's condition, and a treatment plan (if necessary) in a new clinical note saved within the prototype EHR system. The duration to task accomplishment was calculated from when the intern logged into the EHR System to when s/he indicated they had completed the clinical task.

Based on the fact that chronically ill patients expectedly accumulate considerable amounts of clinical documents due to their frequent ambulatory visits and in-patient admissions (126), patient records used in the study were selected from a larger cohort of patients with a diagnosis of diabetes and other comorbidities e.g. hypertension and dyslipidemia. During control experiments in a previous study without the visualization tool (87), six interns reviewed nine patient records with associated clinical scenarios. These patient records were from the University of Minnesota affiliated Fairview Health Services. Each intern scored all the records on a 10 point scale (1- lowest, 10- highest) for each of three parameters: 1) completeness of clinical information within the record, 2) degree to which the record assisted with performing a routine clinical task, and 3) the amount of redundant information within the record. Two clinician investigators (GM and OF) selected four patient records for the study after eliminating outlier records that had mean total scores ≤ 5 or were atypical (e.g. had missed appointments/office visits) compared to the other records. For the purposes of this study, all outpatient progress notes over a one-year period were used for the scenario, which amounted to eight to ten notes per patient record for the four patients selected.

For this study, a different set of eight interns synthesized the selected patient records based on the clinical scenarios. Each intern accomplished one clinical scenario without access to the visualization tool for new information and another scenario using the ‘review changes’ tab to activate the visualization tool (Table 4.2). Interns verbalized their thought processes as they reviewed the patient records and performed the clinical scenarios using the prototype EHR user interface that included the visualization tool. Mock sessions of TA protocol and the use of the ‘review changes’ function was conducted for each intern prior to the observations; these sessions involved a sample clinical scenario different from those used in the observations.

Table 4.2 Design of Clinician Observations in the Think-Aloud Protocol

Clinician ID	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	N		V	
2		N		V
3		V	N	
4	V			N
5	N		V	
6		N		V
7		V	N	
8	V			N

Key
N = No visualization tool
V = Visualization tool used

Following thematic analysis of verbalizations from the TA protocol, average numbers of references under the themes generated from the protocol analysis were compared using the Student’s t-test - a statistical procedure robust enough to adequately handle small sample sizes ($n < 30$) (105). For the t-test, we used an α-level of 0.05 (the probability that observed differences in the average numbers of thematic references may have arisen due to chance); thus, the p-value (the probability of observing a difference in the average numbers of thematic references that is equal or more extreme compared to those calculated) will be statistically significant if less than or equal to the α-level.

We also conducted semi-structured interviews to further identify themes that reflect the possible influences of the visualization tool on interns' efficiency at synthesizing EHR documents as they performed specific clinical tasks. Interns' verbalizations during the experiments were transcribed and analyzed using QSR NVIVO® 9. To determine interrater reliability, another researcher familiar with the coding scheme and experienced in qualitative research (KM) coded a subset (10%) of the study transcripts; there was very good agreement between the investigators for both the protocol analysis ($\kappa = 0.96$, mean agreement = 98%) and the interview data analysis ($\kappa = 0.81$, mean agreement = 91%).

4.4 Results

We observed eight clinical interns (4 males and 4 females, aged 25 – 30 years) as each synthesized two patient records and carried out routine clinical tasks associated with clinic scenarios with and without the visualization tool for new information. To emphasize information synthesis rather than recall, the experiments were designed such that an intern was exposed to a specific patient record and corresponding scenario no more than once.

4.4.1 Protocol Analysis

Prior to our analysis of the think-aloud data (protocol analysis), clinical documents created by the interns at the end of each clinical task were evaluated by a clinician investigator (OF) and found to be appreciably similar in format, length, and clinical details such as history of presenting illness, differential diagnoses and treatment plan..

The average duration based on the total time to task accomplishment when each scenario was reviewed with and without the visualization tool was not statistically different (43 ± 1mins vs 36 ± 5mins, p = 0.26). However, we noted that the there was a much larger difference in the total times to accomplish scenarios 2 and 3, with and without the visualization tool, compared to 1 and 4 (Table 4.3).

Table 4.3 Duration for Completion of Clinical Tasks:

Scenario ID	**Total duration (mins), N = 4**		**P value**
	No Visualization Tool	**Visualization Tool**	
1	41	49	
2	45	26	
3	43	29	
4	44	42	
Mean ± SE	**43 ± 1**	**36 ± 5**	**0.26**

In view of the study objective and recognized frameworks highlighted in software usability studies involving TA protocols (50,83,127), we conducted a protocol analysis by carefully reviewing the study transcripts and noting some themes that aptly represented the interns' information synthesis from EHR clinical documents while completing the clinical tasks. Following several iterations of the protocol analysis, we deductively identified predominant high-level cognitive activities that signified ongoing information processing by the interns. As defined in Table 4.4, interns' verbalizations were exclusively coded based on whether s/he reasoned out an accurate inference (Deduction), expressed a possibility without verifying the statement (Assumption), alluded that s/he could not retrieve existing clinical data necessary for patient care (Missing Information), made an inference that conflicted with available clinical data (Incorrect Inference), or ordered a procedure, test or prescription in line with patient care (Intervention).

Table 4.4 Themes from the Protocol Analysis:

Theme	**Definition**	**Example from Transcripts**
Deduction	accurate inference based on logical reasoning	"So it looks like she has a diagnosis of proteinuria-so that's suggestive of kidney damage due to her diabetes."
Assumption	relevant statement without proof/verification	"Compression stockings- possibly I think that he might have had some problems with neuropathic pain likely related to diabetes in the past, but not entirely sure; maybe he has some circulation problems."
Missing Information	existing clinical information that was not retrieved	"Trying to see what they did for her at this time-which I am not seeing."
Incorrect Inference	inference that disagrees with available information	"No BMI today."(Note: the patient record had a body-mass index (BMI) value in the document)
Intervention	procedures ordered for patient care	"To evaluate for those things I definitely want to first start her with a chest x-ray to evaluate for pneumonia."

Protocol analysis, as shown in Table 4.5, revealed that deductions and assumptions were predominant end points of information processing when the interns synthesized EHR clinical documents in completing designated clinical tasks. Overall, when analyzed per clinical scenario, there was a three-fold decrease in cases of available but unretrieved patient data (missing information) when interns used the visualization tool (2.3 ± 0.9 vs. 6.8 ± 1.1, p = 0.02). In addition, the mean value of incorrect inferences made when the visualization tool was not used (2.3 ± 0.3) was almost twice that observed when the tool was used (1.3 ± 0.3); this difference was also statistically significant (p = 0.03). Differences in deductions, assumptions and interventions revealed a 1.1 – 1.5 factor increase in references coded under these themes when interns did not use the tool; however, the differences in mean values were non-significant (26.8 ± 5.0 vs 28.3 ± 1.9, p = 0.79 (deduction), 7.3 ± 1.3 vs 11.5 ± 1.6, p = 0.08 (assumption), and 6.5 ± 2.7 vs 9.3 ± 1.8, p = 0.43 (intervention)).

Table 4.5 Quantitative Analysis of Themes Identified during the Observations

Themes	**Mean ± SE (Total), N = 4**		**P-value**
	No Visualization Tool	**Visualization Tool**	
Deduction	28.3 ± 1.9 (113)	26.8 ± 5.0 (107)	0.79
Assumption	11.5 ± 1.6 (46)	7.3 ± 1.3 (29)	0.08
Missing Information	6.8 ± 1.1(27)	2.3 ± 0.9 (9)	0.02*
Incorrect Inference	2.3 ± 0.3 (9)	1.3 ± 0.3 (5)	0.03*
Intervention	9.3 ± 1.8 (37)	6.5 ± 2.7 (26)	0.43

∗ Statistically significant (α level = 0.05)

4.4.2 Interview Analysis

To further identify effects of the visualization tool, we interviewed each intern following completion of a sequence of clinical tasks with and without the tool. As indicated in Table 4.6, we identified some themes from the interview transcripts showing the potential impact of the visualization tool:

Attentiveness- some interns commented that the visualization tool helped them carefully consider specific patient information that may have escaped their attention if the clinical documents were reviewed ‘as-is’. However, some interns indicated that the visualization tool could pose a distraction and obstruct the synthesis of aspects of the EHR clinical documents that are not highlighted. Statements to support these perspectives include;

> Positive: “I guess even if some things were important and some things didn’t seem that important but at least, when it was highlighted, my eyes definitely go there and I definitely take note of it.”

> Negative: “It could mislead you because it’s saying that’s the only change and then you don’t know the other things.”

Table 4.6 Frequencies of Themes from the Interviews

Theme	Definition	Positive	Negative	No comment
Attentiveness	focus on details while reviewing clinical documents	5	4	0
Time-related changes	information that signifies changes in health status over a period	7	1	0
Speed	rate at which clinical documents are reviewed	4	1	0
Thoroughness	careful synthesis of portions of the clinical documents	3	1	0
Navigation	maneuvering from one clinical document to another	3	0	1
Total		**22**	**7**	**1**

Time-related Changes- According to majority of the interns, the visualization tool assisted with noticing changes in the patient's clinical condition across time, and constructing a mental model of the patient's progress. Responses that reflected this impression include;

> Positive: "It's helpful to see what had changed. I think that's the information that is most pertinent especially when somebody is coming in."

> Negative: "I think that the vitals are always going to change; so I didn't really think that was useful to have that highlighted at me."

Speed- In most cases, interns implied that the visualization tool was time-saving by facilitating an easier and faster process of going through EHR documents However, interns' perception of speed did not correlate with the average duration of task completion for scenarios 1 and 4. Examples from the interview transcripts include:

Positive: “My experience was that it was a little bit faster going through the note, through all the notes. It kind of helped you weed out some of the extraneous information.”

Negative: “I think I would use it; but it wouldn’t, for me, necessarily make me faster.”

Thoroughness- Responses during the interns’ interviews indicated that, although the visualization tool did not completely eliminate possibilities of missing any patient information, it often motivated meticulous and accurate synthesis of the EHR documents:

Positive: “I think I made a more complete note as I actually was able to review a lot more of the previous notes because of the tool.”

Negative: “I think this time I was just frustrated because I couldn't find the information I was looking for; so I didn’t know if I was just not thoroughly reading the notes.”

Navigation- Comments from the interns signified that navigating between EHR documents while synthesizing relevant patient information was more intuitive with the visualization tool:

Positive: “I found the tool useful to help navigate through the notes. The notes, without the tool, are sort of difficult to find your way around because so much stuff gets blown in from previous notes.”

Negative: None

4.5 Discussion

Information synthesis from lengthy text-based EHR clinical documents using unsophisticated visualization aids may be arduous, time-consuming and error-prone due to complex organization of narratives, excessive redundancy within the documents and possible proliferation of data inconsistencies (33). Ongoing interest in implementing user-centric EHR systems within healthcare organizations inspires the need to systematically address issues related to data visualization towards optimizing clinical information synthesis at the point of care (83,128-130). Previous studies on the design of user interfaces to improve EHR visualization and address cognitive needs of healthcare providers have employed various research methods in establishing solutions for enhanced clinician-computer interaction and efficiency in patient care (66,83,96,131). Using a mixed methods approach, we evaluated the effects of a prototype visualization tool of new (non-redundant) information on interns' synthesis of EHR clinical documents while performing routine clinical tasks using a model ambulatory EHR user interface.

As outlined in table 4.1, scenarios 1 and 4 required the synthesis of EHR documents to develop an admission note, scenario 2 involved summarizing the entire patient record, while constructing a referral based on salient aspects of the EHR documents and scenario was the task in scenario 3. Although the difference in the interns' total duration to task accomplishment with and without the visualization tool was not statistically significant, we observed significantly shorter times for completion of scenarios 2 and 3 with the visualization tool compared to 1 and 4. This suggests that the time to accomplish the clinical scenarios could be influenced by the nature of the task and not just the interns' information retrieval strategies. The two tasks that had essentially the same times were admission tasks where the strategy of highlighting key information may not be particularly useful since large quantities of available patient information may need to be reviewed to adequately capture all clinical events prior to the admission. This is in contrast to writing a referral or a patient summary where easier and quicker access to salient information would be more helpful. Therefore, the time-saving benefit of the visualization tool may be more evident when it is used to perform certain clinical processes. In addition, since the study was conducted in a controlled practice environment, more research is required to evaluate the visualization tool in the context of the multitasking and interruptions in realistic practice settings in order to determine if the tool can address barriers to EHR systems adoption such as increased physician time expenditure and reduced periods of clinician-patient interaction (132-134).

Study results show that the visualization tool can lead to a significant reduction in cases of unretrieved but available patient information and incorrect inferences when interns synthesize EHR clinical documents in line with performing clinical tasks; thus the tool increased the likelihood of well-informed decisions. Despite being statistically comparable, the average number of assumptions was relatively more when interns synthesized the EHR documents without the visualization tool. We presume that the interns' inability to retrieve relevant patient information when the tool was not used could have resulted in the higher number of assumptions, but more evidence is necessary to support this claim.

Other benefits of the visualization tool reported by majority of the interns during some interviews include their enhanced processing of time-related changes in a patient's clinical status, faster navigation between patient details in the EHR, and motivation towards methodical and accurate synthesis of EHR clinical documents when they used the tool.

Overall, the visualization tool demonstrates how future designs of user interfaces for text-based EHR documents can be improved and provides a foundation for research on ways to optimize distinction of new and redundant data within EHR clinical documents towards minimizing errors in synthesis and comprehension of patient information.

Our restricted sampling of interns at the University of Minnesota Medical Center poses a limitation to generalization of the study findings; the results obtained may not adequately represent the potential effects of the visualization tool on the workflow efficiency of interns at other healthcare facilities, more experienced physicians or other non-physician clinicians (e.g. nurses and pharmacists). Further studies are required to corroborate our findings at other medical centers and stages of clinical expertise, and within various healthcare provider populations.

It is important to note that verbal protocols obtained while the interns synthesized electronic clinical text during the TA experiments were not controlled for quantity of speech and the possibility of additional cognitive processes directly related to ‘speaking one’s thoughts’ during task performance. Because the study experiments were conducted within a simulated ambulatory clinical environment, investigations regarding the impact of the tool within realistic emergency, in-patient and ambulatory care settings are required. In addition, the effects of visualization tool on efficiency of non-intern clinicians can be evaluated under time constraints similar to those experienced in realistic settings.

A next step in enhancing the visualization tool will be to combine techniques in our laboratory to develop natural language processing (NLP) algorithms for improved automated detection of new information within EHR clinical documents in a pilot study of an interface in practice to test this with patient care.

4.6 Conclusion

Our evaluation of the effects of a prototype visualization tool of new information on clinicians’ synthesis of text-based EHR clinical documents provides evidence that new information identification in text may reduce the tendency to miss relevant patient information, and therefore increases clinicians’ ability to accurately synthesize patient information while providing care. Further research is recommended to investigate the impact of the tool on workflow efficiency among other clinician populations and within various healthcare settings. Our findings provide groundwork towards more user-centric display of EHR clinical documents using advanced visualization applications.

4.7 Clinical Relevance Statement

Clinicians' use of the prototype visualization tool can reduce the likelihood of omission errors associated with processing large quantities of redundancy-laden EHR clinical documents during clinical encounters. Therefore, the tool can enhance provider efficiency and promote better information synthesis towards effective clinical decision-making.

4.8 Conflicts of Interest

The authors declare that they have no conflicts of interest in the research.

4.9 Human Subjects Protection

The study was performed in compliance with the World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects. Prior to commencement of the study, all selected patient records were de-identified using the safe-harbor method. The study was approved by the University of Minnesota Institutional Review Board (Study Number: 1012E93487).

CHAPTER 5

CONCLUSION

Developing EHR user interfaces that can effectively support the synthesis of clinical documents may require better understanding of the clinicians' cognitive processes involved in integrating poorly organized and potentially conflicting details within these notes (20,135). Carefully consideration of these processes can lead to more user-centric designs of EHR clinical document interfaces that would more easily allow clinicians satisfy their patient information demands during patient care. To address the need for insights into clinicians' cognitive processes during patient care, our first and second studies provided some evidence of information processing patterns from observing clinicians' as they synthesized textual data from EHR clinical documents while accomplishing clinical scenarios in a simulated ambulatory setting.

Based on the cognitive model depicting clinicians' cognitive processes observed in the first study, we discovered that they most often processed information related to patients' problems, treatment and symptoms within EHR clinical documents in order to adequately conceptualize relevant clinical events, generate hypotheses on etiology and disease processes, and make decisions appropriate treatment regimens. Two predominant classes of patient information described as focal points of clinicians' information processing in the first study (Problem and Treatment) were validated by observations in the second study which highlighted clinicians' cognitive processes employed as they reviewed EHR clinical documents with and without time constraints usually experienced in ambulatory care. Therefore, similarities in cognitive processes observed across different clinician subjects and different experiments in the second study support the validity of our conclusions on clinicians' cognitive processes related to EHR clinical document synthesis stated in the first study.

Time restrictions introduced during observations in the second study generally resulted in fewer instances of concepts representing clinicians' information retrieval and processing as they reviewed EHR documents and accomplished designated clinical scenarios. This finding was not surprising in that with restrictions on the time available for task performance, it is expected that one will do relatively less compared to when the limits on time are removed. Also, time restrictions were associated with an emphasis on results of investigative procedures (*Test*), as against a similar focus on the chronology of clinical events (*Time*) under untimed conditions, when clinicians' synthesized information from EHR clinical documents. Study findings showed that restricting the time available for clinicians to review EHR documents did not lead to a significant difference in omission errors or erroneous deductions when compared to their performance of similar tasks under untimed conditions. We noted, however, that the time restrictions employed in this study may have been too extreme for all possible errors to be identified, and recommend further studies involving repeated alterations of the time duration within simulated and realistic clinical settings to analyze the impact time constraints on clinicians' synthesis of EHR documents.

In the third study, we implemented a visualization tool for new information based on our experiential knowledge of specific clinical details that usually change across clinical documents within a patient record as well as evidence from the first study that clinicians' synthesize certain classes of patient information (symptoms, signs, problems, treatment, and tests) and encounter excessive data redundancy when reviewing large quantities of these documents. On activation, the tool enabled color-coded highlighting of changes patients' vitals, signs, symptoms, complaints, problems and plan across all clinical text documents within a patient record. On evaluating the impact of the tool on clinicians' synthesis of EHR documents, we noted that it lead to some improvements in clinicians' cognitive processing including fewer errors of omission and inaccurate deductions. However, because the time-saving benefits of the tool were only evident when clinicians accomplished certain clinical tasks (e.g. summarizing a patient record), we proposed that the visualization tool may have been more useful in some types of tasks than others. The visualization tool for new information, by integrating knowledge of clinicians' cognitive processes in the implementation of visualization techniques in EHR systems, may promote more efficient and effective synthesis of electronic clinical documents

The three studies shared common limitations due to our sampling of a singular category of clinicians (internal medicine interns) practicing at a specific healthcare facility (University of Minnesota Medical Center), observing clinical task performance within a controlled laboratory environment, and restricting simulations to represent only ambulatory care processes. In spite of these limitations, the studies provide insights into the cognitive processes of clinicians employed while synthesizing EHR clinical documents in the context of patient care and evidence that a visualization tool for new information can support effective EHR document synthesis by reducing omission errors and textual data misinterpretation. These findings may be relevant to future research on cognitive and visualization strategies related to EHR document utilization among diverse clinician types within in-patient, out-patient and emergency care settings.

In Gerhard Fischer's article on context-aware systems, he states that human-centered computer applications like the EHR system should not only offer "more information to any user, at anytime, and from anywhere, but should rather make available the right information, at the right time, in the right place, and in the right way to the right person" (136). Researchers in clinical informatics and human-factors also advocate a user-centric approach to investigating and addressing issues related to the organization and display of EHR data to facilitate clinicians' accurate and meaningful information synthesis while caring for severely ill patients (30,31,63). In the three studies above, a rich and fascinating collection of evidence to promote better understanding of clinicians' cognitive processes employed in synthesizing EHR clinical documents and presents a 'shining light' to the way these documents can be visualized to support information retrieval in the context of clinical care. Overall, findings from the studies should inform innovations in future designs of EHR document user interfaces towards enhancing clinician efficiency and satisfaction with EHR systems and improving the quality of EHR clinical document synthesis during patient care.

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