Using Semantic Search to Reduce Cognitive Load in an Electronic Health Record

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Abstract— **As electronic health records (EHRs) become more prevalent in health care further research is needed to understand the efficacy within clinical contexts from a human-computer interaction viewpoint. Participants (N=10) were given two authentic scenarios that required users to search for patient information. In the first scenario, participants responded to a patient-specific information need as they normally would. In the second scenario, participants were given a semantic search tool that indexed terms within a patient EHR. Upon completion, participants were then asked questions in a semi-structured interview about current usage of the EHR. Statistically significant results revealed that participants were able to more efficiently navigate through an EHR in terms of time (semantic search M=140 vs. browsing M=239 seconds) and number of clicks (semantic search M=11 vs. browsing M=35). This study suggests that semantic search capabilities may be a good way to reduce cognitive load within clinical settings for similar patient-specific information needs.**

Keywords - cognitive informatics; information retrieval; medical information systems; search engines

I. INTRODUCTION

Due to advancements in medicine, physicians are caring for an increasingly older and more complex patient population. These more complex patients generate even more information that gets stored within a patient's electronic health record (EHR). Information technologies, such as electronic health records, provide novel opportunities to better support patient care. The information within an EHR requires physicians to be accountable for more information as medical records are assimilated across multiple institutions and systems. However, the efficacy and adoption of the EHR are often derailed by usability issues. One such research gap includes usability issues of EHRs that relate to the limitations of cognitive load and working memory. A smart semantic search within the EHR, embedded in the workflow of the clinician, which helps users navigate the growing data points within, will be a necessary tool of the future to manage cognitive load, increase time savings, and subsequent technology adoption.

II. ELECTRONIC HEALTH RECORDS

A. Cognitive load

The resources available to a physician are limited by time, space, memory, and access to information. Therefore, despite the potential benefits of the EHR to streamline information access, the technology may actually become a deterrent to patient care if not designed in accordance with cognitive load considerations. Previous models of cognition supported in medical informatics have generally focused on the interaction from a human information-processing standpoint [1]. We argue another important paradigm is that of cognitive load theory. This theory suggests that individuals have a limited ability to process and make sense of information [2]. When a physician engages in problem-solving, s/he must consider various elements of the problem such as current symptoms, previous diagnosis, and new patient data. The individual holds this information in working memory while drawing upon prior knowledge. However, working memory is heavily impacted by the number of elements that must be processed. In the context of medicine modern health care setting, a clinician will rely on the EHR to retrieve information to develop a mental model that accounts for the elements of the problem.

Various forms of cognitive load exist. Intrinsic working memory describes the inherent complexity of the problem. That is, the inherent difficulty of the diagnosis or resolution given the presented symptoms and patient history [2]. Alternatively, extraneous cognitive load is additional processing that is unnecessarily added to working memory. Germane load facilitates schema construction. Extraneous load within the interface may detract from individual understanding of the problem [3]. As such, the working memory required to serve the patient may be exacerbated if the physician employs a poorly designed EHR and thus leads to errors in diagnosis and other patient care decisions. Designers of interfaces need to further understand how to facilitate information acquisition and schema formation of the problem.

B. Limitations of the EHR

Despite the potential benefits of the EHR, further studies are needed to assess the usability of these products. Research shows that nearly 30 percent of EHRs have failed in clinical contexts due to a lack of consideration for the human-computer interaction and impact on workflow [4]. The time to navigate and locate pertinent information can consume nearly 20 percent of the diagnostic effort [5]. Some have suggested that the unnecessarily complex presentation of the information may deter patient care and add to the overall work-time [6], [4]. Physicians deem these unproductive and inefficient uses of their time and may further preclude adoption of the system.

Bath [6] argues that it is not necessarily the technology that limits the EHR, but that lack of consideration for the human factors. Given what is known about the limitations of working-memory, it becomes important to seamlessly search and summarize patient information to further reduce barriers to system adoption and ensure that physicians have efficient access to the requisite information needed to support clinical decision-making [7].

C. Semantic Search

Despite the immediate availability of the EHRs, information is not always satisfactory and easily available because it remains difficult for clinicians [8]. To further promote physician adoption and successful use of an EHR, physicians need to be able to search for the correct information within a patient record [9]. Whereas discussions have documented previous research has investigated the importance of search engines for location of medical literature to answer clinical information needs, very little empirical research exists to investigate how physicians navigate through an EHR to find patient-specific information needs.

Although studies have focused on the development of search capabilities to facilitate navigation throughout an EHR [8], [10], [11], the ability of the search to minimize extraneous cognitive load has not been examined. Whereas search helps to find appropriate materials, navigation within the system and selection of appropriate materials still places a strain on working memory. This is particularly crucial for clinical workers and researchers who require the ability to search for descriptions of specific clinical findings from a large volume of clinical documents [12]. One such solution is to utilize a semantic search approach. A user submits the search requests by typing keywords related to a clinical concept and repeatedly adding in multiple relations to build a semantic pattern. The semantic search engine performs the search against the index files according to the user input and returns a list of corresponding documents from the EHR repository.

Despite the potential benefits of semantic searching, more empirical search is needed to verify the efficacy to support physician decision-making. Furthermore, research is also needed to better understand how physicians navigate through an EHR. These findings can help elucidate the technological tools required to better support physicians in practice.

III.   METHODOLOGY

Because patients frequently do not recall all medications that they have taken in the past, the goal of the present study was to identify whether using a semantic search would improve a physician's time to find information as well as the accuracy of a particular diagnosis. As such, two search methods were compared with one another. The first search asked participants to browse for medical information in a patient record as they normally do within the current system interface, which includes multiple windows and lengthy pages of information. In the second method, the participants were asked to find the pertinent information within a separate patient record using the semantic search interface. The semantic search interface provides dynamic suggestions as the individual conducts the search. In addition, the semantic search is cross-linked with other synonymous medical terms (e.g. heart attack and cardiac arrest). As such, the results display multiple relevant returns that are not explicitly stated in the initial search.

A cross-over design was utilized to minimize any potential differences between two separate patient records. Institutional Review Board (IRB) approval was obtained to search two real patient charts in order to more accurately simulate a complex and clinically accurate medical record. Both quantitative and qualitative data were collected to answer the research questions.

A. Demographic Information

The study was completed over the course of two months at a large Midwestern medical university. Prior to the test, a subject matter expert searched through the medical records database to find two similar patients as test cases. In each case, the patient was an elderly patient who had experienced a variety of chronic issues. The selection of an elderly patient was to ensure that the search tasks were realistic and contained similar characteristics. The sample consisted of 10 Family and Internal Medicine physicians. In each session the participants completed two tasks. The first task provided a common clinical scenario to the participant whereby s/he had to verify whether a patient had been on a particular medication (e.g. an ACE-Inhibitor class). Using their current browsing search method, participants sought information in the chart that would be critical to solving the patient-specific information need. After the first task, participants viewed a one-minute video that introduced the semantic search capability. Next, the participants used the semantic search feature to find answers to a similar patient-specific information need of a second patient. Upon completion of the tasks, the researcher conducted a semi-structured interview to further elucidate information seeking behaviors.

B. Effeciency of Task Management

Two measures were employed to determine the technology's ability to support problem-solving. The first measure, time on task [3], [13], was measured to identify how long the participant actually searched for information after the scenario was presented. An additional measure included number of clicks. The number of clicks is an appropriate way to understand the effort expended by the user to navigate through the EHR when searching for the required information.

C. Accuracy of Assessment Measurement

The accuracy of the information gathered to support the participants was measured in terms of perceived accuracy and

actual accuracy. At the end of each task, participants rated their perceived accuracy using a Likert scale.

The second measure included the actual accuracy of the solution based on a subject matter expert. After all interviews were completed, all participant answers were compiled in a spreadsheet. A blinded subject matter expert (KMK) assessed the accuracy of each of the participant's answers for the two tasks. Prior to assessment, the names and search methods were removed to avoid potential biases in assessment.

D. Partcipant Perception Measurement

After the interview participants completed a semi-structured exit interview. Questions identified browsing and search behaviors and how physicians employ technology in current practice. Additional questions were asked of participants for recommendations to further improve the functionality of the semantic search feature.

IV. RESULTS

A. Efficiency of Task

Prior to analysis of the different search methods, patient cases were analyzed to ensure that one patient record did not particularly bias the results. Comparisons between mean time to search did not find statistically significant differences between patient 1 (M=190 seconds, SD=116.3) and patient 2 (M=188 seconds, SD=71.2). Similarly, the mean number of clicks was not statistically significant between patient 1 (M=25, SD=21.1) and patient 2 (M=21, SD=8.5).

After normality was established, a paired-samples t-test was conducted to evaluate whether physicians were supported using their previous methods or with the semantic search. Results of the paired-samples t-test revealed significant differences in terms of the number of clicks with the semantic search tasks (M=11, SD=5.4) when compared with the current browsing method (M=35, SD=13), t(9)=3.96, p=<0.05. Similarly, results of another paired-samples t-test revealed significantly less time (total seconds) when comparing the semantic search tasks (M=140, SD=67.0) with the current browsing method (M=239, SD=91.8), t(9)=6.65, p<0.05.

B. Accuracy of Assessment

To compare the self-perceptions of the assessment accuracy, a paired-samples t-test was completed on responses using a Likert scale from 1 to 5. Results revealed no statistically significant differences between the semantic search perceived confidence (M=4.1, SD=1.9) and the browsing method (M=3.9, SD=1.3), t(9)=-0.29, p=0.78.

The actual accuracy of the assessment was also gathered as another measurement. Upon completion of the interaction with both systems, participants were asked a series of questions about the patient's condition based on information found within the chart. Although the semantic search accuracy was higher (100%) when compared with the browsing accuracy

(92%), no significant differences were found between the two search methods.

C. Participant Perception

The qualitative results indicated that the search would be beneficial for multiple reasons. Physicians noted that searching for clinical information is tedious in the current installment of many EHRs. In many cases, the physicians noted they approached the search task in many ways. When talking about finding information about past medications, a physician expressed doubt in the reliability of the information sources that are reviewed – *"If it's a medication, I go to the med[ication]-profile first, then active meds, then click on the little plus sign that shows past meds. I don't know what that might miss. I don't know how far back that goes. I don't know, for instance, if that includes inpatient meds."*

Others suggested that the information is not always accurate because other physicians do not use the technology appropriately. In each of the quotations above, participants suggested that the information seeking approaches varies widely. Unfortunately, the physicians must spend more time searching patient data because of the lack of trust in how other colleagues use the system. As such, physicians acknowledge that information seeking is a process and thus s/he may overlook information found elsewhere within the EHR.

Given that physicians express doubt as to the efficacy of the information seeking, the research team then asked how the patient-physician behavior is altered. Some physicians noted that they would ask for a paper copy of the EHR or call external sources that might possess the information (i.e. – pharmacy, cardiologist). However, many participants noted that they frequently proceed without the information even though the physician is unclear about the information. The following quotes from multiple participants corroborate this:

"I am likely to just throw up my hands and say. 'I don't have time to dig back through this.' I may end up writing a prescription for an ARB instead of an ACE [Inhibitor], which [then] costs them 10 times as much."

Another participant expressed similar frustration when s/he said:

"I would probably just prescribe the medication if it's the one that I wanted to use and the patient didn't have a strong feeling that they have been on it before or had an allergic reaction. Sometimes I just say 'no. I'm going to make my best medical decision without that information."

As noted in the quotations above, participants often proceed with decisions despite knowing that s/he does not have all of the desired or appropriate information to suggest the most appropriate course of action for the patient.

V. Discussion

Policy makers and health care professionals suggest that increased utilization of an EHR could result in a potential savings of over $75 billion [14]. However, research shows that adoption may be precluded by lack of usability and ease of use [15], [16]. Sittig, et al. [17] notes that key issues for EHR to consider include improvement of the human-computer interface, dissemination in design best practices, summarization of patient level information, and the utilization of free text to drive decision support. The authors of this paper argue that semantic search is one opportunity to achieve the challenges set forth by Sittig, et al [17].

Because electronic health records afford the ability to store additional data, clinicians become responsible for more information. The results of the study further validate previous studies that have highlighted the difficulties of navigating within an EHR [18]. Whereas physicians may quickly traverse a physical medical record, the physicians in the current study support the others who note that interaction is different when patient information is situated within an electronic format [6].

Qualitative data from the study suggests that frustration may cause individuals to make a less-informed decision rather than take the time to navigate the system to find the appropriate information. Because medical institutions are becoming less dependent on paper-based records, the responses about actual use of an EHR from physicians may indicate patient care trends will be problematic in the future. As such, tools such as semantic searches are needed to support the cognitive load and information overload considerations of physicians [9].

Another important finding was the measurement of cognitive load in the form of time on task [3], [13] and the number of clicks. Using both forms of measurement, the findings of this study suggest that semantic search will assist physicians to manage the cognitive load required to navigate within an electronic health record. Given that the browsing task required more clicks and time, this study supports previous research that suggests an EHR may in fact add to the physician workflow rather than improve efficiency [6], [16]. Other studies have highlighted that time required to learn the system acts as a barrier to adoption [15], [19]. It appears as though information accessibility potentially comes at a cost to quality of care given the working memory limitations and time available. As such, this study provides empirical support of search prototypes and suggests additional technological tools are needed to efficiently process all information [10-12].

Although the perceived and actual accuracy of the assessments were higher with the semantic search, the findings revealed no statistically significant differences. One potential explanation of the no significant differences findings is the perceived accuracy may be attributed to the lack of transparency as to how the semantic search actually conducts the queries. Participants questioned what aspects of the EHR were being indexed and what information may not be represented in the search results. It is possible that providing a description or list of the searchable elements of the EHR may have improved the confidence and thus the perceived accuracy. An interesting study would be to ascertain how perceived and actual accuracy improves longitudinally.

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