Cognitive-Task-based Information Aid Design for Clinical Diagnosis

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Abstract. Clinical diagnosis systems are increasingly supported by advanced information technology but enhancing human diagnosis performance with intelligent aiding has not been found guaranteed. Diagnosis is an intense cognitive task for which the supporting intelligent features should be designed and integrated to match human decision process. This study conducted cognitive work analysis to identify the user strategies and needs of information, and designed an effective interface based on a set of design principles for diagnosis aiding. The target system was a medical service that provided comprehensive blood test reviews and diagnosis to local hospitals. An interim evaluation by experts showed highly promising service value scores.

Keywords: Clinical decision support system · Intelligent interface design · Cognitive work analysis

1 Background

Clinical diagnosis systems are increasingly supported by advanced information technology for integration of sub-processes and tasks from initial registration of patients through various tests to diagnostic conclusions. Designing intelligent interface to enhance the human expert's diagnosis is essential in developing an advanced CDSS (Clinical decision support system). If rightly designed, such decision aiding approach may achieve more accurate diagnosis with fewer errors. Brian and Boren [1] reported that 13 studies (76%) out of 17 studies in clinical decision support systems (CDSS) yielded improved outcomes. Garg et. al. [2] conducted a broader survey to report that, out of 97 cases of CDSS, the human performance was enhanced in 62 cases (64%). However, it should be noted that only 4 of 10 diagnostic systems they surveyed were more effective than other types of clinical task support such as reminder systems (76%), disease management systems (62%), and prescribing systems (66%). This result suggests that diagnosis, being cognitively more complex than managerial tasks, does not easily benefit from a computer aid.

The reduction of diagnostic errors is the most important purpose of diagnosis aiding. Many researchers have listed cognitive biases in clinical diagnosis that increased the probability of errors [3,4,5]. Conservatism biases such as anchoring, confirmation bias, diagnosis momentum, and triage cueing lead the decision maker to stick to the initial hypothesis while suppress suggestions for other hypotheses. Satisficing heuristic, premature closure of search, availability heuristic, and representative bias may also contribute to incorrect diagnosis. There are also simpler errors such as slips and lapses. Weakened attention due to mental or visual fatigue tends to increase errors, too.

In this research, we are developing a computer aiding system with intelligent features including partially automated diagnosis, selecting similar cases to compare with, and providing relevant texts in literature that are text-mined with recognized keywords. This paper introduces the development of an intelligent interface that integrates these machine intelligence ingredients and the human expert's decision capability. A cognitive work analysis is conducted to identify the user needs of information and the opportunity of intelligent support. The interface is design based on a set of interaction design principles for diagnosis aiding by a computer.

2 The Task and Cognitive Task Analysis

2.1 The System and Task

SG Company in Seoul provides a laboratory service receiving patient blood samples from hospitals and conducting a comprehensive set of blood tests. Most of the blood samples are collected as a part of routine medical examinations and analyzed in SG laboratories. The medical experts in SG review the test results and conclude comments on the reports. The number of indicator readings is somewhere around 30~50 usually. The task takes less than 5 minutes for most patients, but may require more than 20 minutes when the conclusion is not immediately obvious. Hospitals may apply different range for a same indicator so that the report should accordingly be adjusted.

2.2 Cognitive Work Analysis

Cognitive Work Analysis (CWA) is a comprehensive framework of system analysis developed by Rasmussen [6] to understand complex sociotechnical systems that embraces human decision-making as the essential ingredient. Work domain analysis (WDA), the first stage of CWA, tries to identify necessary functionalities and the relationships among them across functional means-ends layers: system purpose, abstract functions, generalized functions, physical functions, and physical forms.

Figure 1 shows a brief overview of the WDA result of SG Company’s blood test review. The abstract function of *hypothesis management* encompasses all required functions for decision-making to produce diagnostic conclusions based on the measured indicator values. The concluded diagnosis is then dealt with by the other abstract function of *diagnosis management*, which comprises of the report producing tasks considering client requests and other necessary adjustment due to factors outside the indicator readings themselves.

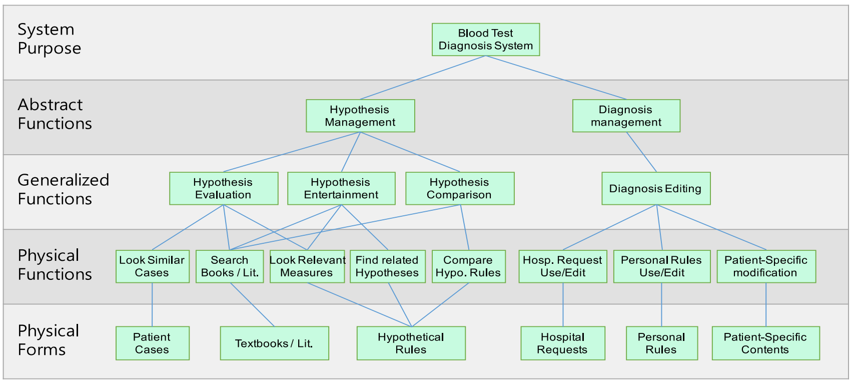
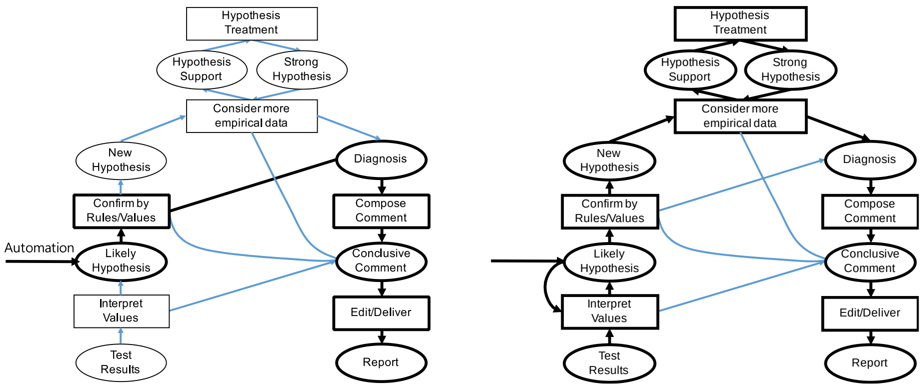


Fig. 1. The work domain analysis of blood test review

The next step in cognitive task analysis is cognitive task analysis. The actual paths of cognitive actions by the human decision maker are described. Two SG experts were interviewed for a variety of cases that demanded different diagnosis strategies.

Figure 2 depicts the SG expert's possible paths of cognitive process identified through the interview in an input-process-output framework. Human experts usually try to follow more economic and reliable paths using shortcuts for obvious choices. Indeed, the most frequent strategy is one shown as bold lines in Figure 2(A). In contrast, Figure 2(B) models the most complicated strategy, where the expert needs to evaluate and select between competing hypotheses. There exist other strategies between the two extremes.



(A) (B)

Fig. 2. Cognitive Task Analysis: (A) Overall framework (B) Pattern recognition (C) Decision table search (D) Hypothesis generation and test

2.3 Information Requirements and Design Principles

The strategy analysis enables us to determine the information needs for each strategy. Aiding features can then be devised to help reduce mental effort and hence error possibility. Information and representation requirements for the pattern recognition strategy shown in Figure 2(B), for example, are summarized in Table 1.

Table 1. Information and representation requirements for pattern recognition

task	Information Req.	Representation Req.
Confirm suggested Hypothesis	• Suggested Hypothesis • Supportive readings • Unsupportive readings • Unrelated non-normal readings	➢ Central and clear ➢ Grouped, Hypo-related ➢ Positivized, Hypo-related ➢ Marked, Hypo-indicating
Compose Comments	• Hospital requests/rules • Personal rules • Patient peculiarity • Importance of results • Certainty of results	➢ Automated modification ➢ Automated / referenced ➢ Highlighted, if any. ➢ Prioritized ➢ Visual scan of strength

We set interaction design principles for effective diagnosis aiding based on the identified strategies:

- Alternative hypotheses for current data should be made easy to access and evaluate.
- Switching hypotheses back and forth should be supported saving working memory.
- Data that are treated together should be visually grouped by position or color.
- Relations between data and hypothesis should be visualized by links or associative highlighting.
- Navigation or operations should be able to exploit visual association (e.g., links).
- Information should be displayed to match the human strategies that are expected to utilize it. Examples are sorting for visual scan, trimming irrelevant data, and highlighting words in text.

3 The design of user interface

Figure 3 shows one of the main user interfaces that was designed upon the above-derived requirements of information and aiding features. In the upper-left part, the interface provides important indicators and their values. To its right hand side is the corresponding diagnosis part and comment part that delivers the results to the client and the patient, respectively. Each part of the interface operates as follows.

1. The values are highlighted when they fall outside of the normal ranges. The degree of deviation is intuitively shown for the expert assessment.
2. The computer suggests automated diagnosis based on the readings. The expert can adjust the diagnosis to one's judgment. Manually choosing a diagnosis item will highlight the related readings in part 1. The ground and the conclusion are clearly shown together.

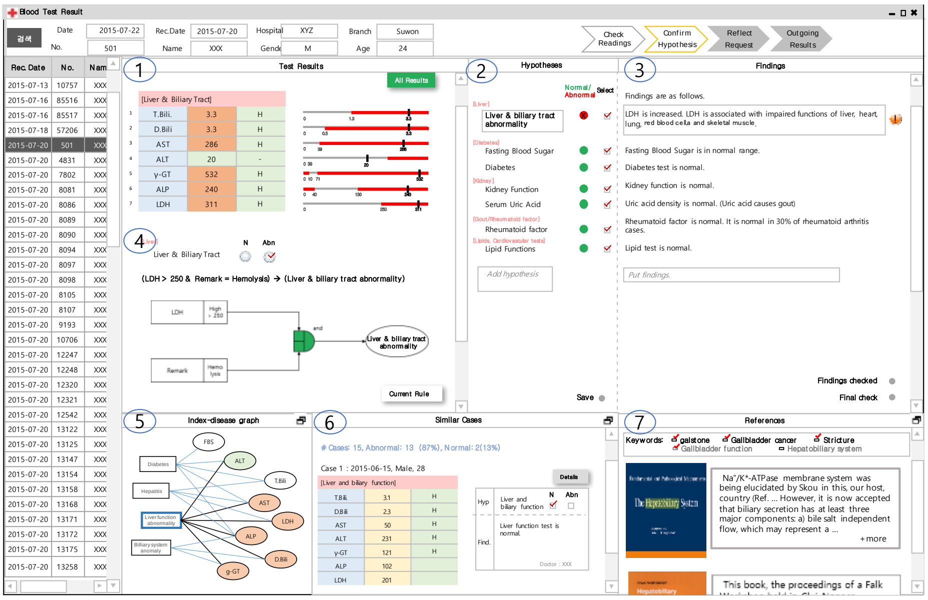


Fig. 3. The aiding interface of SG blood test review

3. The machine generates comments on the basis of the diagnosis. The expert can edit them as necessary.
4. For each hypothesis, the necessary conditions in terms of expected readings are shown in a causal diagram. This visual aid is based on the diagnosis rule base. The expert can easily see what conditions are met and what are not.
5. The indicator-hypothesis network for knowledge navigation. The expert can traverse according to his interest to find out new related hypotheses or the indicators to check.
6. Similar cases recommended based on similarity to the current case. It is very helpful when the conclusion is somewhat ambiguous.
7. Textbook or literature that are automatically searched using the current prominent words in highlighted readings and hypotheses.

As an overall principle, the interface responds to the movement of user attention; when a diagnosis, comment, or indicator is selected by mouse click, all the logically related information panes are changed, selected, highlighted, detailed, or expanded so that the screen remains coherent and informative as a whole.

4 A Brief Evaluation and Conclusion

The system completed its prototype and is currently under a full implementation. A preliminary evaluation, employing SERVPERF [7] was conducted for the service value of the aiding, beyond mere interface usability. Three SG medical experts participated in the evaluation. Since the medical diagnosis task is very professional and specialized task, a non-expert evaluation would not have much value. We performed the evaluation in five facets of the service quality that were paraphrased for the given service. They were (1) Tangibles: does the interface look good and react well, (2) Reliability: is the interaction believable, predictable, and understandable, (3) Responsiveness: does the system provide desired information in right time, (4) Assurance: does the system give confidence in its proficiency (5) Empathy: is the system adaptive for individual needs.

The evaluation was done for six information units (windows) in the display, and for six frequent task elements. On a 7-point Likert scale, the information units scored at 5.85 overall compared with 2.5 in the current system. The task elements, which were helped by the aiding features, were rated at 6.4 in contrast to the current system's 1.7 showing higher acceptance for the actual aiding performance.

It is emphasized that the functions of machine intelligence should be designed to fit human cognitive tasks from the beginning. The features should also be integrated in an interface based on the study of human strategies in particular task domains. After the ongoing full implementation, the system will be installed for actual service by SG Company; then we expect to acquire more evidences for the effectiveness of designed interface.

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