INTERACTION DESIGN FOR MOBILE CLINICAL DECISION SUPPORT SYSTEMS: THE MET SYSTEM SOLUTIONS

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Abstract. The fit to the workflow is an important requirement for the acceptance of clinical decision support systems in practice. Clinical systems that do not satisfy this requirement are likely to be rejected by their users despite their functionality. Disruptions and deviations from the workflow may be avoided by the appropriate and careful design of interactions between the system and its users. In this paper we focus on mobile clinical decision support systems that can be used directly at the point of care for the emergency triage. We discuss the interaction design methodologies used to develop the MET (Mobile Emergency Triage) system that facilitates emergency triage of patients with various acute pain conditions. We use a *scenario-based design* methodology to encapsulate the user's mental representations of tasks to accomplish, and an *Object-Action-Interface model* combined with the *Eight Golden Rules of Interface Design* to design the input and the output components of an interaction framework. We also demonstrate how we have implemented these theoretical solutions.

Keywords: interaction design, Object-Action-Interface model, scenario-based design, handhelds, clinical decision support systems, emergency triage

1. Introduction

According to Simon [1] a decision-making activity is a process that is composed of a set of simpler tasks. These tasks are performed following a pre-defined sequence (a precedence relation) and form a pattern that is often referred to as a *workflow*. This term originates from the design of business processes and usually implies *the automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules*. However, it can be easily transferred into a clinical context where the process of managing a patient is com-

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posed of tasks involving gathering and evaluating information about the patient, followed by applying medical knowledge to decide on the definitive management (diagnosis, prognosis and therapeutic options) appropriate for the patient's medical condition [2, 3]. In this paper we concentrate on the workflow associated with triaging a pediatric patient by an emergency department (ED) physician and use an abdominal pain assessment as an illustrative example.

Let us consider the clinical workflow scenario presented in Figure 1. According to this scenario, the tasks of triaging a patient and their precedence relation are:

1. Examination, including patient's history and physical exam;
2. Recording of history and exam results on the chart;
3. Ordering tests;
4. Reviewing and recording of test results on the chart;
5. Decision making.

> A 6-year old boy is brought to the ED by his parents complaining of abdominal pain. The doctor goes to *examine* the boy, and begins by obtaining the boy's history to ascertain the type, duration and location of pain, as well as associated symptoms (e.g., fever, vomiting). The doctor then conducts a physical examination and checks for abdominal tenderness. She finds that the boy is tender in the lower section and has a fever. The doctor then *records* this clinical information on a paper chart. She decides to *order* blood work to help determine what is causing the pain. After *reviewing* the results of the blood work, the doctor *decides* to admit the child for further in-hospital investigation and observation.

Figure 1. ED workflow scenario

While tasks (1) and (2) are usually performed at the point of care (i.e. the ED examination room), task (3) normally takes place at the nurses' station, and tasks (4) and (5) could either take place in the examination room or in other locations. Such decomposition of the workflow is especially important when the use of clinical decision support systems (CDSS) is considered. The aim of these systems is to help healthcare professionals deal with the constantly growing amount of clinical information that has to be collected, processed and analyzed during the process of evidence-based decision making. Different pieces of this information are available at different stages and locations of a workflow process, and processing of this information by the ED physician requires different modes of support depending on a particular task on hand. If the support functionality of CDSS is well planned and supports workflow processes, it can result in improved patient outcomes [4].

The success of a CDSS is not only dependent on the quality of the decision model used to generate recommendations, but also on the design of the interactions between the system's functions and the end-user tasks. It involves the interplay between users' actions and what a system does in response. In the clinical domain, interaction design should aim at matching clinical tasks identified in the workflow to specific system functions, organizing the communications between users and the system, and then planning the interface [5].

In this paper, we discuss the MET (Mobile Emergency Triage) system [6, 7], a CDSS, which facilitates triage of children with varying acute pain conditions in hospital EDs and we present the MET interaction solutions. MET is designed as a mobile client-server system, with clients deployed on portable and wireless devices. While designing MET system interactions, we paid particular attention to the following issues:

- The system's availability at the point of care,
- Easy and intuitive interaction with the system,
- Alignment of the system interactions with the ED workflow.

The paper is organized as follows. In the next section we give the taxonomy of clinical information systems, and describe interaction design. In Section 3 we discuss interaction design methodology. A description of the MET system and the interaction solutions that support triage workflow within an ED follows, and then we conclude with a discussion.

2. Interactions in clinical information systems

Medical informatics solutions in a broad clinical area can be classified under the umbrella of clinical information systems. The taxonomy of these systems includes:

- Patient information management systems (for management and retrieval patients' records) [8],
- Monitoring systems (for monitoring bodily functions and alerting about abnormal readings) [9],
- CDSS (for providing support in clinical decision making).

Clinical information systems are intended for use in different environments, ranging from the sites of accidents to hospital registration offices, and by diverse groups of users, from secretarial staff to physicians. The diversity of environments and users impacts the way in which a system's interactions should be designed, and makes such a design a challenging task.

Patient information management systems are traditionally used away from the point of care, and are operated mostly by clinical support staff (i.e. nurse practitioners, medical assistants, or data entry clerks) [10]. These systems use data collected by physicians during patients' encounters (patient's history, physical exam and laboratory results) that is usually transcribed from a paper chart by a member of the clinical support staff. As these systems are used away from the point of care, the focus of interaction design has been to facilitate entering data by creating usable interfaces.

Monitoring systems, especially those integrated into medical devices, are usually deployed at the point of care [9, 11]. The nature of these systems makes it very important to design interactions so the clinician becomes alerted of critical situations, avoids making mistakes, and reacts properly to the alerts. Design guidelines for such systems are governed by legal regulations [12], and are often augmented by very specific instructions on how to create user interfaces to minimize the possibility of an error [13].

The third type of clinical information systems, CDSS, are used to provide patient-specific assessments or advice based on clinical data [14]. CDSS are underrepresented in clinical settings as most of them have been developed as research projects, intended mainly as proof of concept, and therefore, they have not been tested in practice [15, 16]. Only a few have been introduced into daily clinical routine [17, 18]. These systems, similar to patient information management systems, have traditionally been used away from the point of care, and their interactions design was focused on designing the interface, rather than fit with the workflow.

It is important to stress here that many clinical information systems have been withdrawn from practice because of their poor interaction design. They were often awkward and time consuming to use [19], they were unavailable when needed [20], or they required healthcare professionals to adapt to the system rather than the reverse [19]. Recent advances in mobile computing technology and interactions design have made it possible to create user-centered systems that are available at the point of care to be used by clinicians when and where it is necessary, offering easier integration with the clinical workflow [21].

3. Methodology of interaction design

3.1. Framework of interactions

There are four major elements that form the general framework of interactions [5]: *the system, the user, the input,* and *the output*. Each component has its own representation (e.g., for the user, it is the mental description of the task he/she wants to accomplish). The cycle of an interaction includes the following mappings of the representations associated with each component (Figure 2):

- *Articulation* – mapping user's mental representation to the input requirements,
- *Performance* – mapping input representation into a computer-readable representation,
- *Presentation* – mapping system's results into the output representation,
- *Observation* – mapping the output representation into the user's mental representation.

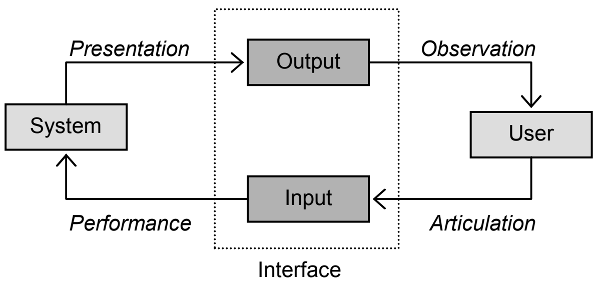

Figure 2. The general framework of interactions [5]

For a successful interactive system, the interface component should help articulate the user's mental concepts (articulation) so that they are accepted by the system (the input), and the results of the system's operation should be presented (the output) in such a way that the user can easily map them (observation) into his/her mental concepts. Thus, the main issue of interaction design is to properly capture the user's articulation, and to support the user's observation in the interaction framework. Note that the system's representation is not as important because the associated mappings (performance and presentation) do not involve the user, and the difficulty in their design is confined to computational complexity.

Shneiderman [22] developed a basic taxonomy of requirements for designing the interface components (the input and the output elements) of the interactions: (1) high-level theories, (2) middle-level principles, and (3) specific and practical guidelines. He states "the theories and models offer a framework or language to discuss issues that are application independent, whereas the middle-level principles are useful in creating and comparing design alternatives. The practical guidelines provide helpful reminders of rules uncovered by designers."

Following this taxonomy, we used *scenario-based design* [23] and an *Object-Action-Interface model* [22] as the general theory behind the MET interactions; *domain-specific design* [24] as a middle-level principle; and well-established guidelines, like the *Eight Golden Rules of Interface Design* [22], and specific interface solutions for mobile devices [25] as the practical guidelines.

3.2. Scenario-based design methodology

Scenario-based design relies on scenarios that describe how users might accomplish their tasks with the help of the system. Thus it is a very useful methodology for exploring a user's mental tasks. Scenarios, developed with the significant involvement of the users, are represented as primary design requirements. They are created before the actual system is developed, and they focus on the expected functionality of the system. Scenarios can also be applied to design the system's functionality, and to evaluate and review specific design solutions in order to check if all the usability goals have been satisfied.

As scenario-based design is concerned with how users execute tasks in their totality, it can be seen as encompassing *user-centered* [26] and *task-centered design* [27], which are used in the development of interactions for CDSS. The former exploits cognitive commonalities among the class of potential users and identifies specific features of the system that need to be in place to meet user requirements. The latter involves supporting only representative tasks that users perform, thus resulting in a system that is easy and intuitive to use.

3.3. Object-Action-Interface model

The *Object-Action-Interface* (OAI) *model* offers a way of designing the input and output representations by using knowledge about the user's mental description of the task. It is based on the principle that each task can be associated with a set of objects and a set of actions that manipulate these objects. According to this model, each object that composes the user's task needs to have its equivalent as an interface object, and each action on the task object needs to have the equivalent of an interface action. Such 1:1 mapping should guarantee that all user tasks could be easily accomplished with the help of the interface, as each object and action constituting a mental task will have its interface equivalent.

Applying the OAI model to the interaction framework presented in Figure 2 implies that articulation represents a 1:1 mapping between task objects and actions to input objects and actions, and observation represents a 1:1 mapping between output objects and actions to the objects and actions that comprise the user's mental task.

3.4. Eight Golden Rules of Interface Design

One aim of interaction design is planning the interface of the system. Shneiderman [22] proposes the following eight rules which were derived heuristically from experience:

- Designing for consistency for actions that occur in similar situations,
- Designing for expert users by providing shortcuts,
- Designing dialogs with clear start and end points,
- Designing for feedback,
- Designing for error handling,
- Designing for actions' reversal and backtracking,
- Designing for users' empowerment,
- Designing for short-term memory limitations.

Application of these rules guarantees proper translation of the observation and articulation mappings so the interface design enhances the interactions.

4. MET: A CDSS aligned with a workflow

4.1. The MET system

MET is a CDSS that facilitates the triage of children with varying acute pain conditions in hospital EDs [6, 7]. It uses patient-specific information about the condition (information about a patient's history, physical exam, and the results of the laboratory tests) to support the initial triage decisions outlining what type of clinical management is necessary. Invoking the triage support function (irrespective of the amount of available information about the patient's condition) returns a triage recommendation along with a categorical strength factor (low, medium, high) as to whether the patient: should be discharged home, needs to be admitted for further observation or investigation, or requires urgent specialist consultation. The triage recommendation is generated from a rule-based model created with knowledge discovery techniques from historical patient ED chart data [28].

MET supports tasks (2), (4) and (5) from the triage workflow described in Section 1, namely recording of history and examination findings, review and recording of test results, and making the triage decision. It is designed following the client-server paradigm with the client running on mobile devices. This allows these tasks to be supported at the location where they typically occur (i.e., in the examination room), thus, the physician is not taken away from the patient to complete them. Moreover, the server exchanges information with other hospital information systems (HIS) – it automatically retrieves patients' demographic data and transfers information collected during the examination back to the HIS so they are available for use at later stages of the patient management process, and by other healthcare providers. Such integration not only saves physicians from performing unnecessary and mundane tasks like entering demographics, but it is also considered to be one of key factors in the successful deployment of the CDSS [15, 29]. Finally, MET does not follow a sequential path to derive at a recommendation, but allows users to enter information as they deem necessary, and it is capable of providing a triage recommendation at any stage in the decision-making process (i.e., despite missing information for some clinical findings).

4.2. MET interaction design

The fact that MET is designated for use in the ED poses specific requirements in designing the interaction between the system and its users. MET offers patient-specific advice directly at the point of care where medical personnel are under pressure to make quick and accurate triage decisions. Therefore, it must not only become part of the workflow, but it also must allow interactions that let clinicians operate it easily, quickly, with no cognitive burden, and with minimized opportunity for misinterpretation. The design of MET interactions adheres to these requirements by ensuring clinical tasks are matched to system functions, communication between users and the system is appropriately organized, and that the interface is simple and easy to use.

Whereas, the majority of CDSS discussed in the literature are designed to support clinical tasks away from the patient's bedside, the MET system provides the point of care support using handheld computing devices. However, entering information and running the triage function on a handheld computer should not be an obstacle to performing regular examination and assessment as this will result in poor quality of care.

To design MET interactions, we began by observing physicians performing the triage task, including recording information on paper charts and making triage decisions. Normally, following a patient's registration in the ED, the physician takes a paper chart filled with demographic information retrieved from the hospital information system, evaluates the patient, records his/her findings on the chart , then makes a triage decision regarding further possible investigations and management. We used these observations to develop several plausible scenarios of the interactions, as specified by the scenario-based design methodology.

Analysis of scenarios led to the selection of the OAI methodology. The specific OAI model for the emergency triage task is illustrated in Figure 3 (for the sake of clarity, we provide only selected mappings between actions). According to this model, the patient is characterized by clinical attributes that in turn are described by their values and optional notes. Triage of a patient involves two types of activities – recording the values of clinical attributes grouped into three categories: symptoms (patient's history), signs (results of physical exam), and tests (results of laboratory tests), and formulating a triage decision upon acquiring a sufficient amount of information. The values of attributes can be supplemented with notes containing additional information. As with the traditional paper based charts there is no fixed or approved sequence of activities in which the values should be entered.

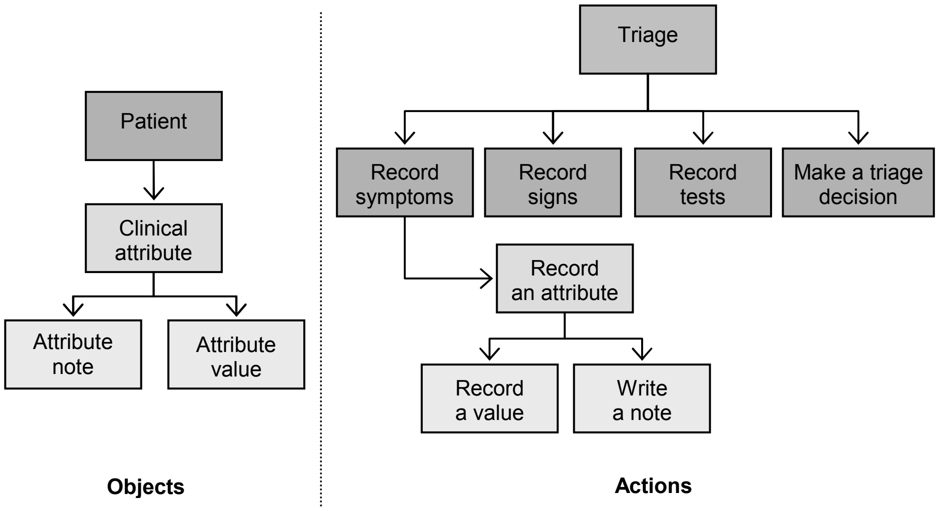

Figure 3. The OAI model for the triage task

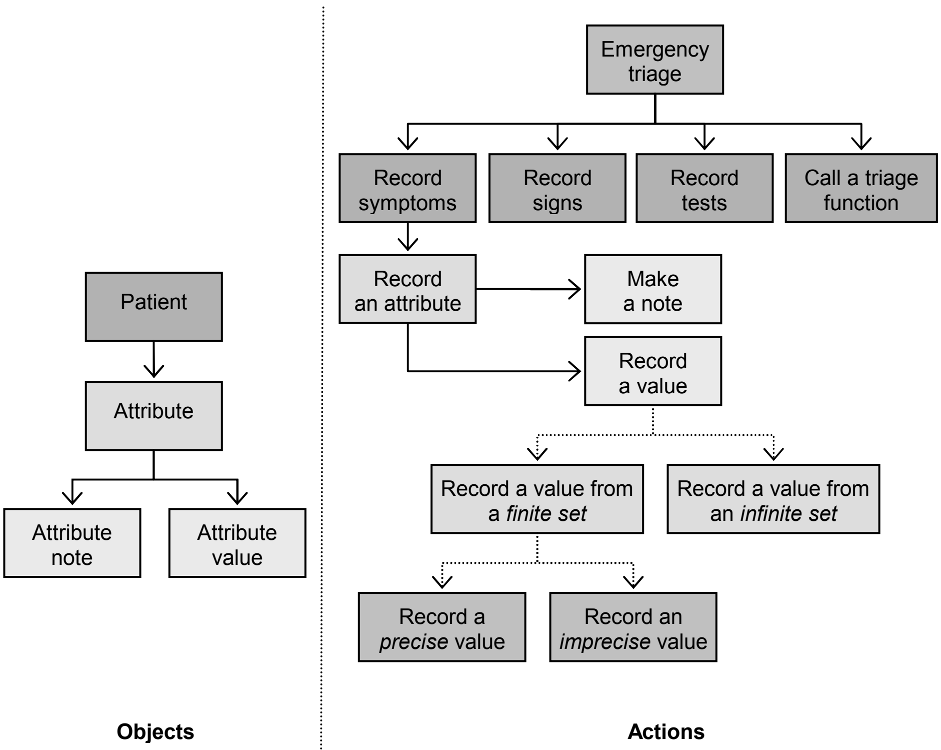

Figure 4. The OAI model for the interface

The OAI methodology was also used to establish a set of interface objects and actions that correspond with the triage task model. The hierarchy of interface objects is the same as that for task objects and the only extension of the OAI task model involves detailed specifications for the action of recording the value of an attribute. This is illustrated in Figure 4.

The OAI model was implemented in MET following the principles of domain-specific design, and interface solutions adhered to the Eight Golden Rules of Interface Design. ED physicians are accustomed to a paper-based system where the results of laboratory tests and patient-specific clinical data are recorded on paper charts. ED physicians are unaccustomed to performing these tasks while operating a computer (especially a handheld with handwriting recognition). To allow clinicians to maintain their familiar workflow and perform their tasks as required, design of MET interactions mimicked the workflow with an ED paper based system and involved domain-specific metaphors (e.g., pictograms, symbols, codes and shortcuts) to represent the interface objects and actions.

As interface actions directly correspond to task actions, there is no pre-defined sequence of activities – attributes can be evaluated or recorded in any order, and a physician may invoke the triage function at any stage of the decision making process. To minimize the potential obstruction of the triage task, the system offers easy navigation between main actions: reviewing the patient's symptoms, recording the signs, evaluating the tests, and calling for the triage support. Each of the functions is immediately and easily accessible – it takes only one user action to invoke each of them. This is consistent with the Eight Golden Rules of Interface Design which state that the most frequent actions should be exposed to the user [22], and with specific guidelines for developing applications for medical devices [13] and handheld computers [25]. These functions are labelled with the names and codes used on paper charts: history (Hx) for symptoms, physical exam (PE) for signs, tests/investigations (Ix), and triage (TR) accordingly (Figure 5).

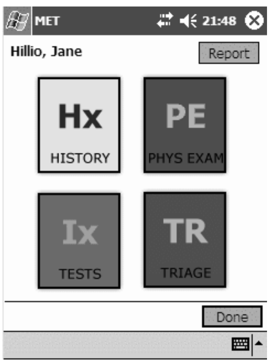

Figure 5. Navigation between main triage actions

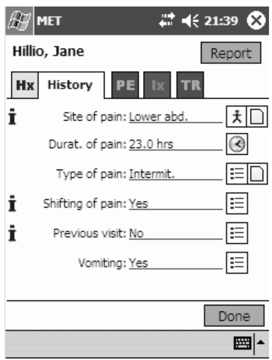

Figure 6. Navigation between recording attributes

On the lower level of interaction, for recording attributes, the physician has direct access to both entering values and making notes (Figure 6). The action of recording a specialized value is implemented in the MET system using the *menu selection* style for the finite set actions, and *form fillin* style for the infinite set actions [22]. The menu selection style requires the possible choices to be understandable and distinct. In practice, the precise distinction may be difficult to achieve because of the observer-dependent bias, and it may lead to recording imprecise values, e.g., the same location of pain may be described by one physician as the lower abdomen, and by another as the right lower quadrant. To address this problem, we further specialized the action of recording the value from the finite set into recording a precise or imprecise value. Precise values can be clearly distinguished and identified, so it is sufficient to record them by using a simple menu selection list without any additional explanation (Figure 7).

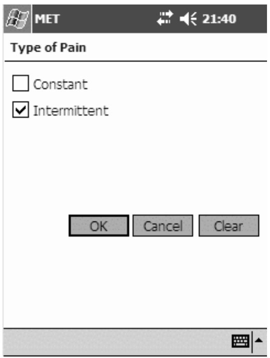

Figure 7. Recording a precise value

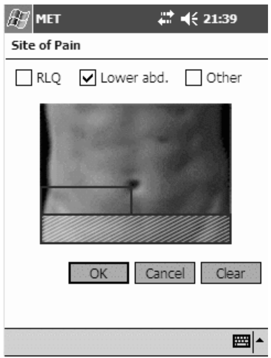

Figure 8. Recording an imprecise value

An imprecise value does not allow for accurate specification, and thus recording it requires additional support. For the abdominal pain triage task, imprecise values are associated with the attributes indicating the location of the clinical condition on the abdomen. Therefore, we decided to supplement the lists of values with pictograms of appropriate body parts to introduce consistency, and to diminish the potential for ambiguous interpretation. Moreover, to ease interactions, the menu selection style was augmented with *direct manipulation* [22], so that a value can be selected directly from the list, or by tapping a corresponding section of a pictogram (Figure 8).

When implementing the *form fillin* style for recording the value from an infinite set, we decided on a solution that does not rely on handwriting recognition for data entry. As all the values coming from an infinite set are numerical (for example, results of laboratory tests), we implemented the recording action using a numeric keypad that mimics a phone or a calculator pad (Figure 9), but we also allowed that advanced users should be able to use shortcuts, so it still is possible to enter such values using handwriting recognition.

The action of recording the note associated with a given attribute's value is logically similar to recording a value from an infinite set. Thus, when implementing this action we followed the form fillin style, and to save the user from extensive use of the handwriting recognition system or the virtual keyboard, we created a glossary of commonly used terms that can be used to compose abbreviated note statements (Figure 10). The glossary was developed from the analysis of hundreds of paper charts, extracting frequently used terms and expressions from notes made by physicians in the charts. However, the user can easily modify it by adding new entries or deleting less frequently used ones.

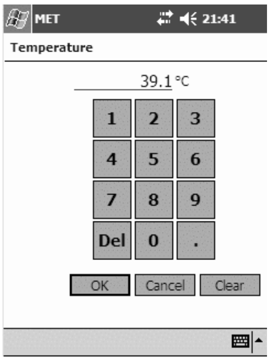

Figure 9. Recording a value from an infinite set

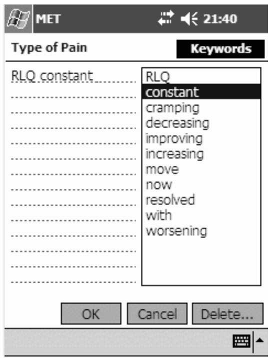

Figure 10. Recording a note

The triage recommendation provided by MET should serve as a reminder for possible triage outcomes. It should also reflect the non-deterministic nature of clinical reasoning. Considering that, and empowering the physician with the ability to have complete control over the system, the triage function returns all possible triage decisions together with associated categorical strength factors [7] (Figure 11). The strongest recommendation is indicated as the suggested triage. Presenting multiple recommendations further stresses the percept that it is the MET user that makes the triage decision; the system just provides additional information to be evaluated.

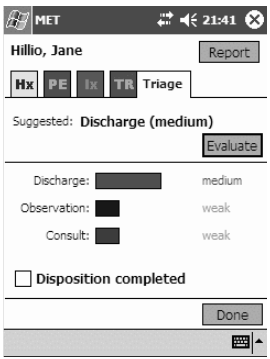

Figure 11. Evoking a triage function

5. Discussion

5.1. Clinical trial

The MET system described in this paper was tested in the ED of the Children's Hospital of Eastern Ontario (CHEO) [30]. The trial lasted for 8 months and involved triaging patients with abdominal pain. During that period 2255 patients with abdominal pain visited the ED, and 574 participated in the trial (the others did not satisfy eligibility criteria, or were not triaged using the MET system). Feedback received from the patients and physicians was very positive. Approximately 150 physicians (ED physicians and residents) used MET to enroll patients and record clinical findings, with many users remarking that using MET did not involve any additional examinations or tests, and did not lengthen patients' stay in the ED. The overall triage accuracy of the system was similar to that of the ED physicians (72% vs. 70%).

The MET users, who participated in the clinical trial, had diverse prior experience with handheld computers, ranging from novice to advanced users experienced with medical applications. All users participated in short orientation sessions and were able to operate the MET system after this session without any difficulties. They were satisfied with the design of interactions and with the system's fit to the clinical workflow. Such positive practical experience further justifies our approach applied to designing MET interactions for use at the point of care.

In the clinical domain, it is very difficult to develop a controlled clinical trial for evaluating the interactions. This is especially true for the ED environment where the nature of the work and constant time pressure on the healthcare providers do not create testing opportunities that are available for business applications. For these reasons focused empirical evaluation of the MET interactions was not possible. However, the successful integration of the system with the existing ED workflow and the positive feedback of residents and clinicians using the system during the clinical trial suggest a successful interaction design.

5.2. Conclusions

Medical professionals often view a CDSS as requiring too much learning, changing the way in which they perform their routine tasks, and not meeting their needs. If there is any cognitive burden associated with the usage of a system, the less likely it will be accepted [31, 32]. In fact, several attempts at introducing CDSS in hospital settings have failed because the systems imposed unacceptable changes to the workflow [14, 33] and the end users found them too cumbersome to use. It was, therefore, important that the MET interactions support cognitive tasks of ED physicians, allowing the interactions to be timely, intuitive and natural.

The MET system allows interaction to take place while an ED physician performs the patient interview and physical exam or reviews the results of laboratory tests, providing for a seamless transition between the data gathering and data entering actions. The use of easy-to-carry handheld computers that can be operated at the point of care, when and where MET is needed, avoids interruptions to the clinical workflow. Physicians using MET do not have to leave the patient in order to obtain triage recommendation, and the use of the system can easily become part of their routine.

Scenarios of MET usage and the OAI model of interactions were developed through observations and confirmed through the consultations with the medical residents, ED physicians and paediatric surgeons. This end-user involvement in designing the system, combined with adherence to well-established principles of human-computer interactions, allowed us to create a set of interactions that are intuitive, easy to follow, and aligned with the tasks of triaging a patient. Moreover, the proposed solution supports the collection of the patient's data in a structured manner, and contributes to organizing and structuring the decision-making process. Several clinical studies [34, 35] demonstrated that structured data collection improves diagnostic performance. This factor alone should not be overlooked when designing the interaction for a CDSS.

Finally, we would like to note that although the presented approach was used to build a system for a handheld computer, it can be easily modified to fit any target platform. Reliance on Shneiderman's taxonomy of requirements for interaction design imply that only specific guidelines need to be modified so the system may be ported to another platform. For example, the requirement for easy and intuitive navigation is specified at a high level but it can be implemented on a handheld computer with graphical buttons invoking necessary functions, and on a mobile phone with the keys on the keypad assigned to these functions. We are currently working on the ontological engineering solutions to further simply the portability of interaction design process.

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References

[1] Simon, H. A., *The New Science of Management Decision*, Prentice-Hall, 1977.

[2] Mueller, M. L., Ganslandt, T., Frankewitsch, T., Krieglstein, C. F., N., S., Prokosch, H. U., Workflow analysis and evidence-based medicine: towards integration of knowledge-based functions in hospital information systems, in *Proceedings of the AMIA'99 Annual Symposium*, 1999, 330-334.

[3] Warner, H. R., Toronto, A. F., Veasey, L. G., Stephenson, R., A mathematical approach to medical diagnosis: application to congenital heart disease, *JAMA* **177**, 3, 1961, 177-183.

[4] Hunt, D. L., Haynes, R. B., Hanna, S. E., Smith, K., Effects of computer-based clinical decision support systems on physician performance and patient outcomes: a systematic review, *JAMA* **280**, 15, 1998, 1339-1346.

[5] Dix, A., Finlay, J., Abowd, G., Beale, R., *Human-Computer Interaction*, Prentice Hall, New York, 1998.

[6] Michalowski, W., Slowinski, R., Wilk, S., MET system: a new approach to m-health in emergency triage, *Journal on Information Technology in Healthcare* **2**, 4, 2004, 237-249.

[7] Michalowski, W., Slowinski, R., Wilk, S., Farion, K., Pike, J., Rubin, S., Design and development of a mobile system for supporting emergency triage, *Methods of Information in Medicine* **44**, 1, 2005, 14-24.

[8] Sittig, D. F., Kuperman, G. J., Fiskio, J., Evaluating physician satisfaction regarding user interactions with an electronic medical record system, in *Proceedings of the AMIA'99 Annual Symposium*, 1999, 400-404.

[9] Brown, D. S., Motte, S., Device design methodology for trauma applications, in C. M. Karat, A. Lund, J. Coutaz and J. Karat (eds.), *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI 98)*, New York: ACM, Los Angeles, USA, 1998, 590-594.

[10] Folz-Murphy, N., Partin, M., Williams, L., Harris, C. M., Lauer, M. S., Physician use of an ambulatory medical record system: matching form and function, in *Proceedings of the AMIA'98 Annual Symposium*, 1998, 260-264.

[11] Holzman, T. G., Computer-human interface solutions for emergency medical care, *Interactions* **6**, 3, 1999, 13-24.

[12] Wiklund, M., *Human factors design process for medical devices: National Standard ANSI/AAMI HE74:2001*, U.S. Food & Drug Administration, 2001.

[13] Wiklund, M., Making medical devices more user-friendly, *Medical Device and Diagnostic Industry Magazine* **5**, 1998, 177-186.

[14] Anderson, J. G., Clearing the way for physicians' use of clinical information systems, *Communications of the ACM* **40**, 8, 1997, 83-90.

[15] Musen, M. A., Shahar, Y., Shortliffe, E. H., Clinical decision support systems, in E. H. Shortliffe, L. E. Perreault, G. Wiederhold and L. M. Fagan (eds.), *Medical Informatics. Computer Applications in Health Care and Biomedicine*, Springer-Verlag, 2001, 573-609.

[16] Shortliffe, E. H., *Computer-based Medical Consultations, MYCIN*, Elsevier, New York, 1976.

[17] Ramnarayan, P., Tomlinson, A., Rao, A., Coren, M., Winrow, A., Britto, J., ISABEL: a web-based differential diagnostic aid for paediatrics: results from an initial performance evaluation, *Archives of Disease in Childhood* **88**, 2003, 408-413.

[18] Barnett, G. O., Familglietti, K. T., Kim, R. J., Hoffer, E. P., Feldam, M. J., DXplain on the Internet, in *Proceedings of the AMIA'98 Annual Symposium*, 1998, 607-611.

[19] Yoder, J., *The Role of Human-Computer Interaction in Medical Information System: Principles and Implementation of MEDIGATE*, Masters Thesis, University of Illinois at Urbana-Champaign, 1992.

[20] Zupan, B., Porenta, A., Vidmar, G., Aoki, N., Bratko, I., Beck, J. R., Decisions at hand: a decision support system on handhelds, *Medinfo* **10**, 2001, 566-570.

[21] Shiffman, R. N., Karras, B. T., Pen-based, mobile decision support in healthcare, *ACM SIGBIO Newsletter* **19**, 2, 1999, 5-7.

[22] Shneiderman, B., *Designing the User Interface. Strategies for the Effective Human-Computer Interaction*, Addison Wesley, New York, 1998.

[23] Carroll, J., *Making Use. Scenario-based Design of Human-Computer Interactions*, The MIT Press, Cambridge, Massachussets, 2000.

[24] Gulliksen, J., Sandblad, B., Domain specific design of user interfaces, *International Journal of Human-Computer Interaction* **7**, 1, 1995, 135-151.

[25] Microsoft Corporation, Pocket PC User Interface Guidelines, http://msdn2.microsoft.com/en-us/library/ms854763.aspx, 2005.

[26] Lewis, C., Rieman, J., Task Centered User Interface Design: A Practical Introduction, http://www.acm.org/~perlman/uidesign.html, 1994.

[27] Raskin, J., *The Human Interface*, Addison Wesley, New York, 2000.

[28] Wilk, S., Slowinski, R., Michalowski, W., Greco, S., Supporting triage of children with abdominal pain in the Emergency Room, *European Journal of Operational Research* **160**, 3, 2005, 696-709.

[29] Ramnarayan, P., Britto, J., Paediatric clinical decision support systems, *Archives of Disease in Childhood* **87**, 5, 2002, 361-362.

[30] Farion, K., Michalowski, W., Rubin, S., Wilk, S., Correll, R., Gaboury, I., Prospective evaluation of the MET-AP system providing triage plans for acute pediatric abdominal pain, *International Journal of Medical Informatics*, 2007, (in press).

[31] Anderson, J. G., Jay, S. J., The diffusion of computer applications in medical settings, in J. G. Anderson and S. J. Jay (eds.), *Use and Impact of Computers in Clinical Medicine*, Springer-Verlag, New York, 1987, 2-14.

[32] Counte, M. A., Kjerulff, K. H., Salloway, J. C., Campbell, B. C., Implementing computerization in hospitals: a case study of the behavioral and attitudinal impacts of a medical information system, in J. G. Anderson and S. J. Jay (eds.), *Use and Impact of Computers in Clinical Medicine*, Springer-Verlag, New York, 1987, 224-237.

[33] Gertner, A. S., Webber, B. L., TraumaTIQ: online decision support for trauma management, *IEEE Intelligent Systems* **13**, 1, 1998, 32-39.

[34] Glas, A., Pijnenburg, B., Lijmer, J., Bogaard, K., de Roos, M., Keeman, J., Butzelaar, R., Bossuyt, P., Comparison of diagnostic decision rules and structured data collection in assessment of acute ankle injury, *Canadian Medical Association Journal* **166**, 6, 2002, 727-733.

[35] Guerlain, S., LeBeau, K., Thompson, M., Donnelly, C., McClelland, H., Syverud, S., Calland, J., The effect of a standardized data collection form on the examination and diagnosis of patients with abdominal pain, in *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, Human Factors and Ergonomics Society, Minneapolis, 2001, 1284-1289.