Supporting Medical Planning by Mitigating Cognitive Load

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Summary

Objectives: Developing a care plan for a patient is a complex task, requiring an understanding of interactions and dependencies between procedures and of their possible outcomes for an individual patient. Decision support for planning has broader requirements than are typically considered in medical informatics applications. We consider the appropriate design of software to assist medical planning.
Methods: The likely cognitive loads imposed by planning tasks were assessed with a view to directly supporting these via software.
Results: Five types of cognitive load are likely to be important. A planning support system, REACT, was designed to ameliorate these cognitive loads by providing targeted dynamic feedback during planning. An initial evaluation study in genetic counselling indicates that the approach is successful in that role.
Conclusions: The approach provides the basis of a general aid for visualizing, customizing and evaluating care plans.

Keywords

Patient care planning, decision making, user-computer interface

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1. Introduction

In medicine most actions are not undertaken in isolation but form part of an ongoing care plan for a patient. However, work on clinical decision support typically concentrates on single, isolated medical decisions (for example, what drug to prescribe, or whether to refer a patient to a specialist). While this work is able to draw on a considerable body of research on the cognitive processes people use when making decisions (e.g. [1-3]), the cognitive processes involved in planning have historically been less well studied. This is beginning to change however [4], and in this paper we report work on a computer system designed to support people making and manipulating complex plans, based on cognitive considerations.

Creating plans of any kind is a complex and demanding activity because it involves the selection and sequencing of multiple actions over time, it may involve significant levels of uncertainty about whether or when events will occur, and may need to allow for actions having unexpected consequences and interacting in complex ways. In medicine these difficulties may be compounded by the need for clinicians with different specialisms to cooperate in planning, and the increasing desire to include patients in the planning of their own care [5].

Some work has been done to characterize the cognitive processes involved in naturalistic planning tasks. Working memory and executive processes are heavily involved [6], the number of variables and interactions within a plan appear critical, and skilled planners form only relatively simple mental plans ([3], p 52). There is also evidence that the level of detail in which a planner considers the future consequences of planned actions influences their plans [7, 8].

2. Objectives

Appropriately designed computer displays can aid performance in cognitively demanding tasks by providing a form of "external cognition" [9], for example by making constraints on the task implicit in the display [10, 11] so that users do not have to internally process those aspects of the task (parts of the task can therefore be "offloaded" to the display [9]). External representations can reduce memory load in problem solving [12]. Our aim in the present work was to design a computer system to directly support the cognitively demanding aspects of plan manipulation in this way.

We would expect planning to impose a greater load on cognitive resources such as short-term (or working) memory and reasoning than simple decision-making tasks. At least five specific types of load are likely to be significant in typical treatment planning tasks:

Firstly, a planner must hold the current state of the plan in memory while it is manipulated. It is well established that human short-term or "working" memory is severely limited in capacity.

Secondly, the planner must identify which options for action are available at each step in the plan. The options will typically depend on prior actions in the plan, and identifying them is likely to require "mental simulation" of the plan [3].

Thirdly, the planner must decide which of these possible actions should be chosen as the next step in the plan. Conventional decision support research can provide guidance on the type of information needed here. There are many approaches to this type of decision support but we have found an *argumentation logic* approach (in which reasons for and against a decision are articulated and

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presented to the user) to be effective in this role [13]. Argumentation appears to be particularly appropriate in clinical planning applications, where potentially complex relationships and interactions must be represented to the user.

Fourthly, the planner clearly needs to keep track of dependencies and interactions between planned actions. Adding an action to a plan may require earlier actions to be changed so that preconditions on the action can be met, and later actions to be changed in order to allow for the possible consequences of the action.

Finally, a planner must keep track of the effect of the plan as a whole with respect to overall clinical goals. Analysing the combined effect of the multiple actions that make up a plan involves further demands on memory retrieval and reasoning [3].

3. REACT

We have developed a software system called REACT (Risks, Events, Actions and their Consequences over Time), its design directly informed by the sources of cognitive load outlined above. Figure 1 shows the graphical interface, which provides four types of decision support each intended to allow the user to "offload" one or more of the cognitive load types:

- Past and future planned events are shown against a time line on an interactive planning chart. The user can drag with the mouse to move, resize, add or delete events. The chart allows the user to externalise the first and second cognitive load types, memory for the current plan configuration and identification of options for action (as each available option is provided with a horizontal "lane" in the plan, see Fig. 1).
- Arguments for and against each proposed action are continually displayed (see Fig. 1) allowing the user to review the pros and cons of each planning decision in the context of the overall plan (the third cognitive load type).
- Visual feedback of conflicts between planned actions and constraints on actions is given continually while actions are being manipulated on the planning chart. This allows the user to externalize the fourth cognitive load type, tracking constraints and dependencies.
- Feedback of the predicted effect of the developing plan on quantitative outcome measures such as risk is given continually during planning (via one or more displays such as the line graphs shown in Fig. 1), allowing the user to externalise the fifth load type, tracking of the consequences of the plan.

The intention is to allow the user to easily explore the "space" of options available within the plan with immediate feedback of the various interactions and consequences. We expect this to be particularly helpful to users who are not very familiar with the planning domain, and also in situations where an expert user must explain their reasoning to a non-expert stakeholder, such as a patient. Immediate visual feedback, continually provided while the user manipulates the plan, is essential to encouraging this exploratory mode of use.

4. Implementation

The REACT computational architecture comprises an argumentation engine which operates on four data objects:

An *instance data object* includes all information relating directly to a particular occasion on which the software is used, for example patient data.

A *plan data object* represents the care plan worked on by the user. It changes in response to actions of the user in the planning display.

A *domain knowledge base* specifies all knowledge relating to a particular clinical application, and comprises a set of *logical arguments* [13] for and against various claims. Arguments may relate to reasons for or against planning particular actions, to the effect of actions on outcome measures (for example overall risk or cost of the plan), and to ordering constraints between actions or events in a plan. For example arguments may be made that particular actions or events must or must not occur before, after or simultaneously with other actions or events.

The arguments have the following form: *Condition* → (*Type*, *Text*, *Arithmetic function*, *Backing*)

Condition is a logical condition that is tested against the current state of the plan. If it is satisfied, text in the *Text* field is displayed to the user, and the *Arithmetic function* field can optionally provide a function to be applied to a specific numerical value (such as a risk graph). The *Type* field indicates whether the argument counts in favour of a planned action or against it, or simply provides additional information. It determines the symbol against the text in the display ("arguments and warnings" in Fig. 1). Finally the *Backing* field allows the authority upon which the argument is made to be recorded – typically this will be a reference to a study in the medical literature, and may link to a URL to open the relevant paper, for example, in a web browser. Detailed domain specifications have been produced for two medical applications, for counselling women with BRCA1 or BRCA2 gene mutations (which lead to high risk of breast and ovarian cancer), and for management of type II diabetes (comprising about 450 and 150 arguments, respectively).

The argumentation engine continually evaluates the conditions of all arguments in the domain knowledge base given the current state of the plan and instance data. The corresponding *Text* and *Arithmetic function* fields are used to continually update the user's graphical display with plots of outcome measures, browsable lists of valid arguments for and against each action on the plan, and visual indication of conflicts and warnings.

5. Evaluation

Our initial evaluation of REACT has taken two routes. To assess our cognitive load hypothesis a focussed experimental psychology approach is most appropriate. To establish usability in a clinical setting, and to gain a more qualitative assessment of the success of the approach via clinicians' attitudes to the software in use, we have used a simu-

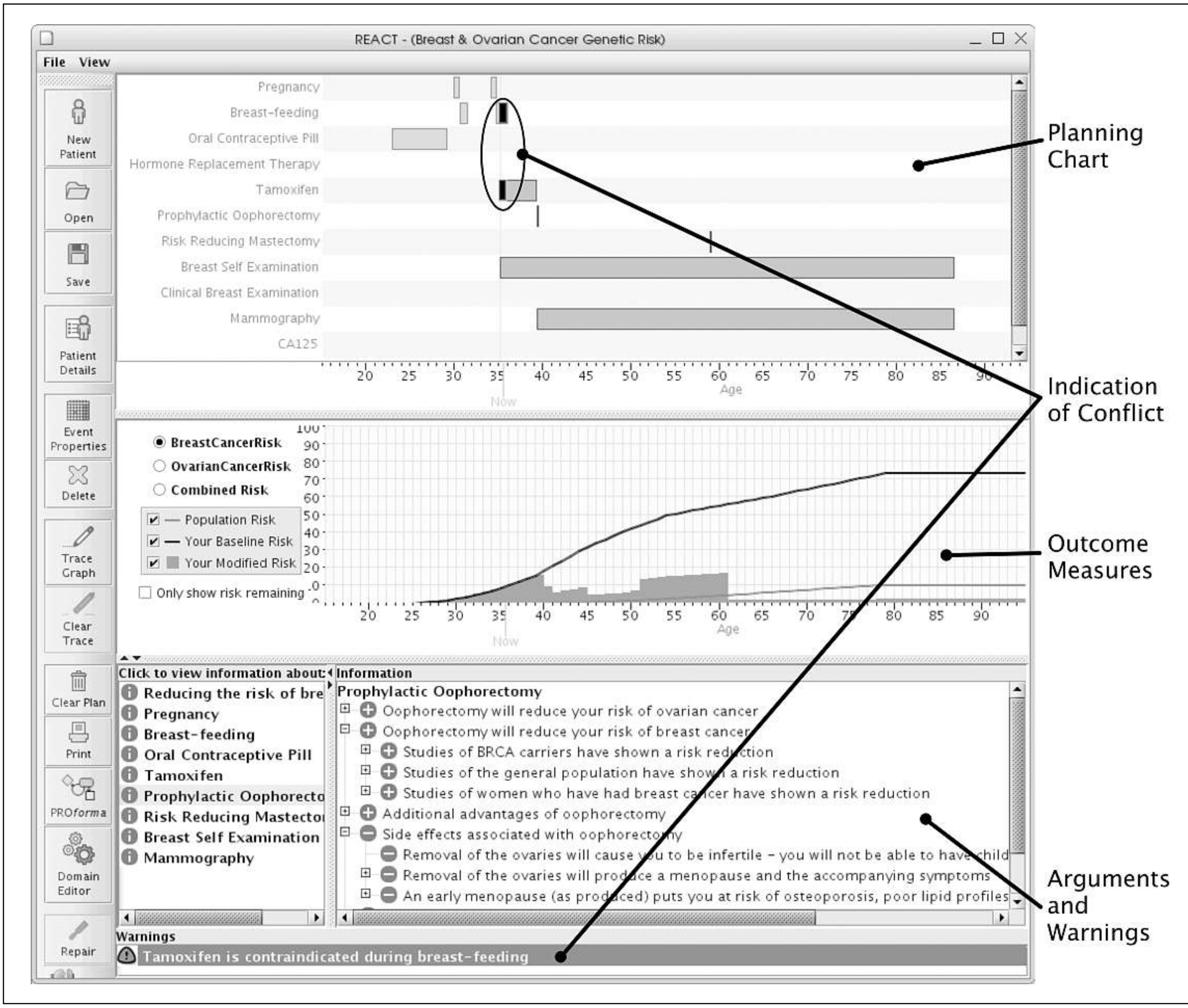

Fig. 1 The REACT user interface. A plan is being developed for risk mitigation in the domain of genetic predisposition to breast cancer by manipulating actions in the planning chart. The outcome measure graph indicates the estimated risk of death due to breast cancer, while arguments for and against prophylactic oophorectomy for this patient are reviewed in the argumentation area.

lated clinical setting. Here we summarise these studies, which are separately reported in more detail.

Firstly, in [14] we test the hypothesis that working memory load is involved in several aspects of planning and examine the degree to which participants can offload aspects of planning tasks to external representations. A series of planning problems of increasing cognitive load was presented while levels of support for key cognitive loads were manipulated. Three conditions provided, respectively, no feedback, feedback in the form of the REACT graph display, and graphs plus the REACT display of constraints and interactions. If these types of support specifically ameliorate working memory load, they should be less beneficial to participants with high working memory span. Therefore, phonological and visuospatial working memory span measures were also administered. The planning problems were based on simple hypothetical medical treatment scenarios, which were fully explained to the participants, forty undergraduate psychology students.

As levels of planning support increased, so did plan quality (defined as a composite of effectiveness of the plan in reducing medical risk, and number of constraint violations). Furthermore, as task complexity increased, the effectiveness of the support provided by graph and constraint feedback increased. Finally, low-span participants benefited more from feedback than high-span participants, supporting the notion that the feedback ameliorates working memory load.

Secondly, in [15] we report a preliminary evaluation of REACT in a simulated genetic counselling setting. Two simulated patients were each played by a professional actor. They played women diagnosed as carrying a mutation to the gene BRCA1, which confers a high lifetime risk of developing breast or ovarian cancer. A number of options may be available for mitigating this risk, and typically a genetic counsellor will work with the patient to produce an individual care plan that reflects her needs. The participants (eight cancer genetic counsellors at Guy's Hospital, London) were each given brief initial training before two testing sessions, in each of which they counselled one of the simulated patients. In one session REACT was used, the counsellors operating the software while sharing the screen with the "patients".

Participants' attitudes were assessed by questionnaire and semi-structured interview. A number of significant themes emerged. Seven out of eight participants expressed a positive attitude towards the use of REACT in counselling sessions. Participants saw a number of benefits: They found that the dynamic visual display put across information clearly and concisely, that logical arguments provided useful "bullet-points" for discussion; and that access to accurate, detailed and up-to-date patient-specific information was empowering. Two counsellors commented that the software helped them to improve the structure of their consultations. The software proved easy to use and to learn.

A number of concerns were raised. Some related to problems participants expected patients to have with the information display, for example the interpretation of graphs. Participants were concerned about possible changes in the dynamics and content of the consultation, and were unsure how much information should be given to the patient. Encouragingly, the participants themselves offered solutions to the problems that they raised. They identified the need to be selective in the use of REACT, both in terms of which types of patients would benefit and when within the counselling session the computer should be used. Participants also felt that they would need to acquire some new counselling skills in order to use the software effectively. However overall the benefits of REACT were felt to make this investment worthwhile.

6. Discussion

Both of the evaluation studies done to date must be considered preliminary. However they provide broad support for our approach. The first study [14] supports the proposition that cognitive load, including working memory load, is a significant factor in planning performance and that it is effectively mitigated by the types of support REACT provides. The second study [15] confirms that the software is usable in a clinical setting, and that clinical users appreciate the features which were motivated by consideration of likely cognitive load.

We expected that genetic counselling, an activity focused on the clinician-patient relationship, would be a challenging area to introduce computer support. Indeed before the study (but after training) most participants were sceptical. However after the study seven of the eight participants were enthusiastic about using REACT clinically. We found this change in counsellor attitude particularly interesting: Using the software in a realistic encounter with a simulated patient was clearly a different experience for the participants than using it alone or during training.

Clinicians' attitudes were more positive than is perhaps typical for decision support software. Indeed negative reactions have been analysed in some detail, e.g. [16]. One factor may be that the software supports them in their task – explaining a complex situation to a patient – without attempting to do the task for them. Another may be that (unlike [16]) there is no compulsory aspect to use of the software. Clinicians spontaneously treated it as a tool to be used when they felt it appropriate.

Other software is available which supports planning, and systems have been designed to provide feedback on plan quality, e.g. [17]. REACT differs in its explicit attempt to allow "offloading" of the five hypothesized cognitive loads of Section 2. The instantaneous feedback of constraints and interactions, effect on global outcome measures and arguments for and against actions allow a mode of use in which the user actively explores the options available within the plan, in a way that is quite distinctive.

We plan to make a number of improvements following the initial evaluation study. Two changes will between them address the majority of difficulties the participants had with the software: The ability to compare multiple versions of a plan by switching between them, and the ability for the user to add or hide "lanes" on the planning chart for specific action types, so that the view of the plan may be tailored to best explore a particular issue or query.

7. Conclusions

Manipulating plans, either directly during planning, or when making decisions which must be considered in the context of wider plans, is we believe an important aspect of medical decision making. As scientific knowledge in all fields of medicine develops at an ever-increasing pace the amount of information a practitioner or patient must take into account in order to make well informed and optimal plans increases dramatically. It is likely that the requirement for some form of computer support for clinical planning will increase.

Initial evaluation indicates that the REACT software is clearly usable in the context of genetic counselling, and it was well received by counsellors. We see the system as potentially useful over a wider range of applications, however, and with a variety of different modes of use. Generally, we believe that the approach will be an effective way to enable people to understand and manipulate clinical plans in the increasing number of situations where this is important. We believe that software to remediate the types of cognitive loads we have discussed in this paper has the potential to become an essential tool in many areas of medical practice.

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