EFFECTS OF SCHEDULING ORDER IN A COLLABORATIVE MEDICATION SCHEDULING TASK

BY

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THESIS

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ABSTRACT

The importance of self-care management was increasing, posting more responsibility to patients, especially for older adults. Successful self-health management often included taking medication as prescribed with good medication regimen. Taking medication as prescribed requires developing medication plans and prospective memory to execute the plan accordingly. This process would especially post challenges to older adults, who typically took multiple medications because of age-related cognitive declines and inadequate collaboration and communication with providers. The e-MedTable provided a common ground to assist patient-provider collaborative planning by integrating patient's daily routine and medication information on the tool. The validity and usability of e-Medtable was also tested in previous researches.

The authors used the tool e-MedTable to investigate simulated patient and providers' problem solving strategies to solve medication scheduling tasks. The first experiment explored users' interface interactions with e-MedTable by mouse click data. Four medications were presented on the tool from the top to bottom. The results revealed that two thirds of pairs followed the order on the tool from the top to the bottom and one third of pairs used alternative orders to solve the problem.

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CHAPTER 1: INTRODUCTION

Medication errors are a leading cause of preventable medical injuries, posing a threat to patients' safety. The report from Institute of Medicine (IOM) *To Err is Human* estimated that at least 44,000 people, and possibly as many as 98,000 people, died in hospitals annually due to preventable medication errors (Kohn, Corrigan, & Donaldson, 1999). The lower estimated number, 44,000 people, still exceeded the number that's attributable to 8th leading cause of deaths in America (*Deaths: Final Data for 1997. National Vital Statistics Reports*, 1999) and was larger than the people died in the motor vehicle accidents (43,458) and breast cancer (42,297) in a given year (*Births and Deaths: Preliminary Data for 1998. National Vital Statistics Reports*, 1999). This report also suggested that medical errors are not only due to mistakes made by health care providers. The complexity of the health care system and complex interactions among different specialists contribute to mistakes, causing serious adverse events. This finding suggests that improving system design that will improve safety by reducing the likelihood of people committing errors, or mitigate the effects of errors.

Medical errors can occur at any stage of care, such as misdiagnosis, wrong-patients and wrong-sites surgeries, post-operative care and medication errors. Medication errors can occur during prescribing, dispensing, administration and patient self-care management. Over the past few decades, there has been an increasing trend for self-care and home health care. With advanced development and improvement of efficacy in pharmaceutics, more and more medications can be taken to treat diseases such as hypertension and diabetes that once were treated with more invasive or risky techniques. As a result, patients need to take more medications to maintain their health. According to the survey conducted by Kaiser Family Foundation, the average number of prescription medicines per capita was increased from 7.9 in 1994 to 12.3 in 2005 (Kaiser Family Foundation, 2007). As a result, taking medications as prescribed becomes a vital component of efforts to maintain or improve health, especially for older adults with chronic illness. They take more prescribed medications compared to younger adults (Barker, Flynn, Pepper, Bates, Mikael, 2002). Taking multiple medications can tax cognitive abilities such as working memory, processing speed and prospective memory. Patients need to understand medication instructions, integrate information about multiple medications, create and implement plans for taking the medications based on patients' daily routine. Patients either develop the medication plans by themselves or with their family, but often without any aid. Older adults may take medication less successfully because of age-related declines in cognitive ability (D. C. Park & Jones, 1997). In other words, those patients who are most likely to have complex self-care needs may have fewer cognitive resources to meet these needs. One way to help patients to take medication as prescribed is to improve communication between patients and providers (Apsden, Wolcott, Bootman, & Croenwett, 2007).

The aim of my thesis was to investigate a tool that supports patient/provider communication about medication, which may improve self-care management by older adults. In this thesis, I investigated the impact of an external tool as an environmental support for collaborative problem solving between providers and patients, so they could create more accurate plans for taking medication. Ideally, patients and providers pool their knowledge to create adherence plans. During the visit, providers have knowledge about medications and treatments and patients have their daily routines as well as their perspective own their illness and treatment experience. Effective planning requires integrating this knowledge during collaboration.. The tool provides a platform for sharing this information, which helps to make the communication more explicit. By providing this platform, the patient and provider can be "on the same page" and focus more on scheduling medications without needing to remember basic information which may tax working memory (Morrow, Raquel, Shriver, Redenbo, Rozovski & Weiss, 2008).

This tool is a computerized version of the MedTable, called the e-MedTable. The original version of MedTable is a paper tool found to improve collaborative medication planning (creating schedule) in a simulated collaborative patient-provider planning task because it helped structure the task by visualizing both time and medication constraints on scheduling (Morrow, et al., 2008). A computer-based version of the medtable was developed and compared to the paper MedTable using the same task, with some evidence that both were more effective than a less structured tool (simple list of medications) using the same simulation task (Waicekauskas, 2010).

The present thesis builds on the findings from these earlier studies in couple of ways: First, structured tools (E-MedTable and MedTable) significantly improved the problem solving accuracy of a pair more compared to a pair using a less structured paper tool (MedCard). Second, structured tools decreased patients' and providers' subjective workload more compared to a less structured tool. Third, limited evidence showed that participants who used structured tools perceived better quality of communication compared to a less structured tool. As a result, structured tools did help pairs to effectively solve medication problems and was a desirable tool for patients and providers (Waicekauskas, 2010). However, the process of solving medications problems with structured tool still remained unclear. This first part of this thesis will analyze the data for mouse click behaviors collected from previous study (Waicekauskas, 2010) to give a preliminary understanding about older adults' strategies in the medication scheduling task. More specifically, we are interested in how patients and providers collaboratively solve the problem in a simulated patient-provider situation. Even though medication information was presented from the top to the bottom on the tool, patients and providers didn't always use the information in this order. The order of medications they scheduled when solving the problems represents their strategies to approach the problem. They would either start with the medication with a lot of constraints or the medication with least constraints. In the second part of this thesis, an experiment was conducted is to understand the effect of the order of medication information on older adults' problem solving strategies. We are interested in whether older adults' problem solving strategies will change if we present different orders of medication to them. The ultimate goals of this study are 1) Identify medication scheduling processes involved in collaborative scheduling task. 2) More practically, develop recommendations for presenting medication on collaborative tools in order to help patients create medication schedules more easily.

Organization of Thesis

Chapter 2 is the literature review about issues of medication adherence, factors that influence medication adherence, patient/provider collaboration needed to create adherence plans and solve medications scheduling problem and their problem solving strategies. Chapter 3 provides an overview of the method used in Waicekauskas 2010 and in the follow-up experiment described in this thesis. This includes describing the scheduling tools and the tasks used in this study. Results of additional analyses from (Waicekauskas, 2010) that investigate possible problem solving strategies are also described. To apply these results, I further construct the difficulty of medication scheduling tasks based on the previous finding. Chapter 4 describes Study II, which examined whether the order of presented information and different types of medication problems influenced the problem solving strategies and performance. Chapter 5 discusses the theoretical and practical implications of the thesis findings and suggests future studies.

CHAPTER 2: LITERATURE REVIEW

2.1 Medication Adherence

Medication adherence is generally defined as the ability to follow medication regimens as prescribed by the providers (Osterberg & Blaschke, 2005). The word “adherence” is preferred here instead of “compliance” because “adherence” incorporates broader meaning for partnership and cooperation, while “compliance” suggests that patients passively follow the doctors‘ orders and medication instructions without actively participating in developing the therapeutic regimen with doctors or the consensual agreement established between patients and providers (Vermeire, Hearnshaw, van Royen, & Denekens, 2001).

With rapid development and increasing effectiveness of pharmaceutics, practitioners increasingly rely on these medications to treat a wide range of diseases, which increase patient’s self-care responsibility to manage their illness (DiMatteo & DiNicola, 1982; DiMatteo, Reiter, & Gambone, 1994). About half of Americans take at least one prescribed medication (Mitchell, Kaufman, & Rosenberg, 2007). According to the Medical Expenditures Panel Survey, the number of prescriptions that was filled (including refills) by adults over 65 annually was increased from 19 to 32 between 1996 and 2010 (Ray, 2002). A recent study found that 90% of woman older adults take at least one medication and about 20% take more than 10 (Kaufman, Kelly, Rosenberg, Anderson, & Mitchell, 2002).

The frequent use of so many medications creates opportunity for error. Low adherence to prescribed medications is very common, with reported rates ranging from 26% to 59%, which imposes a heavy financial burden on the medical system (Botelho & Dudrak, 1992; van Eijken, Tsang, Wensing, de Smet, & Grol, 2003). The average cost of nonadherence has been estimated at $100 billion per annum in the United States (G. Levy, Zamacona, & Jusko, 2000; McDonnell & Jacobs, 2002). Nonadherence also results in worsening of diseases and increased hospital stays, hospital admissions and health care expenditures (McDonnell & Jacobs, 2002; Rodgers & Ruffin, 1998). About 50% of older adults didn't take their medications as prescribed (Haynes, McKibbon, & Kanani, 1996). Medication nonadherence is a complex problem caused by many factors.

Based on the multi-factors model proposed by Park & Jones (1997), factors that would influence medication adherence behaviors can be grouped into three main categories: (1) medication and disease, (2) individual differences in patients' abilities and (3) health care system.

Medication and disease

Medication adherence can be influenced by medication and disease factors such as regimen complexity, side effects of drugs, and illness representation. First, regimen complexity is often defined as how many times a day patients need to take medication and number of medications should be taken each. Different medications often require different schedules with different constraints such as taking with full stomach, taking before meals and so on. Other odd dosing schedules might involve large quantities of pills but only be taken once per week (e.g. methotrexate for rheumatoid arthritis). As a result, the more medications patients are taking, the more likely that they need to take more times in a day and more constraints to keep track of in order to take their medications safely. The complexity of medication schedules may tax patients' cognitive abilities because they need to develop medication schedules that address constraints and to remember to take medications at the appropriate time. Regimen complexity map especially challenge patients with limited literacy (Wolf, Curtis, Waite, Bailey, Hedlund, Davis, Shrank, Parker & Wood, 2011). Patients in that study who had lower health literacy created medication schedules with more times a day than necessary, introducing more complex multidrug regimens. This result suggested that patients with low literacy had trouble creating effective schedules for multiple medications, making the medication task more complex than necessary.

Second, the unpleasant side effect of drugs can influence adherence. For example, there is significant nonadherence among people who take antidepressants (Maddox, Levi, & Thompson, 1994). Experiencing side effects of drugs would discourage patients from taking medication as prescribed. Older adults are especially susceptible to side effects and drug interactions when they didn't take medication as prescribed because the metabolism rate is less rapid compared to younger population (Jernigan, 1984).

Third, patients' understanding of the disease and benefits of taking medication as prescribed and risks of treatments have influence on medication adherence (D. C. Park & Jones, 1997). Patients need to assess whether taking medications as prescribed is worth the effort. For example, they may consider the extent to which the illness disrupts their daily life or whether the perceived benefit of taking the medications as prescribed offsets the costs such as money, time, and side effects.

Individual Differences

Each individual has their own characteristics and abilities that can influence medication adherence, such as age, socio-economic status, health literacy and cognitive ability (M. Levy & Mermelstein, 1982; Morrow & Wilson, 2010). Although the public usually believes that older adults have higher rates of nonadherence, the results are actually inconsistent. Indeed, several studies used pill counts to measure older adults' medication adherence and results did show high rates of nonadherence (Botelho & Dudrak, 1992; White, 1980), but other studies did not (D.C. Park, et al., 1999). This inconsistency suggests medication adherence depends on more than one factor. For example, type of illness or symptoms may be more important than age alone. Several studies do not show a clear impact of socio-economic status on medication adherence. For example, some studies found that financial difficulties predicted nonadherence (LeSage & Zwygart-Stauffacher, 1988). The costs of medication or copayment plan also have influence on medication adherence. However, other studies found that nonadherence was significantly associated with higher socioeconomic status in older adults (Coons, Shehan, & Martin, 1994). As a result, impact of socioeconomics status might be underestimated in many studies. Patients' beliefs about diseases have been shown to have impact on medication adherence behaviors. Beliefs about whether illness is an important factor influences medication adherence behaviors (D. C. Park & Jones, 1997). If the patient believes that he won't get sick in the future, the probability of nonadherence would be increased. Misconceptions about illness also will have impact on the adherence behaviors such as incorrect understanding about illness (acute vs. chronic) and consequences of nonadherence, causes of illness also could predict health outcomes (Ross, Walker, & MacLeod, 2004).

Taking medication as prescribed requires many cognitive processes. As Park (1992) noted: accurate medication adherence has 4 steps. (1) Patients need to correctly comprehend the medication information. (2) They need to integrate all the individual medication information into a medication plan. (3) In order to take medication correctly, they also need to retain the information in their memory. (4) Based on their memory or the notes they take, they will execute medication plan accordingly, which may require their prospective memory.

Education, health literacy and cognitive ability tend to be associated with adherence behaviors. Usually, education is highly correlated with literacy and health literacy (Baker et al, 2000). Because of lower education and poor literacy, individuals might have trouble understanding health-related information, which could result in nonadherence.

The first challenge that older adults are faced with is to understand medication labels correctly. This is also related to patient's health literacy and literacy. Health literacy is defined as the ability to obtain, understand, and navigate the health information and based on the information people received to make appropriate health decision (Nielsen-Bohlman, Panzer, Hamlin, & Kindig, 2004). Inability to correctly understand medication information and labels would definitely have impact on the medication adherence. Patients with lower scores on health literacy tests will have problems to understand the medical terms, which predicts nonadherence. Older adults with lower health literacy would have more problems to understand health related information medication instructions and labels (Wolf et al. 2006). For example, Kendrick and Bayne (1982) found that only 22% of older adults could correctly interpret what *take every six hours* means.

Second, older adults integrate multiple medication information into comprehensive schedules with their daily routines. One study suggested that older adults have some problems to develop strategies to take medications when the medication regimens were more complex (Law & Chalmers, 1976; Wolf et al., 2010). While organizing information, individuals need to retain the medication information and instruction in their working memory and then integrate information about the multiple medications into a plan that matches medication constraints and their daily routine. This task can tax their working memory capacity, so that patients cannot focus on implementing their medications into their daily routines. This task may especially tax process older adults because of age-related declines in cognitive resources.

The last step usually involves prospective memory, which is defined as remembering to remember (Winograd, 1988). Patients need to keep their intended goals active in memory, monitor the time or events as cues to execute appropriate actions. A common reason for nonadherence is prospective memory failure, or forgetting to take prescribed doses (Morrell, Park, Kidder, & Martin, 1997). Previous research has found that successful medication adherence is associated with integrating medications schedules with the patient's routine, such as breakfast, lunch time or dinner time which serves as event-based cues to take medication (Einstein & McDaniel, 1990).

System Factors

Factors related to health care systems such as financial costs, pharmaceutical practice, and communication between patient and providers alsoinfluence medication adherence (Morrow & Wilson, 2010). Some people choose not to continuously take drugs due to high cost of medications. Different insurance coverage plans also had influence on medication adherence (Balkrishnan, 1998).

Pharmaceutical practice includes medication labeling and packaging drugs. The former is related to whether people can understand label correctly in order to create appropriate adherence plans. But in practice, some labels are easily misinterpreted, especially for people with lower health literacy (Davis, 2006). In fact, several studies have focused on improving medication labels by using more explicit and unambiguous language (Wolf, 2007). The latter is related to how the pharmacy packages the drug and deliversit to patients. Applying the unit-dose packaging is one way to help patients to take medication as prescribed and was proved to improve health outcomes (Apsden, et al., 2007). Patients didn't need to split the pill by themselves and pills are easy to be carried around. Also, fewer doses per day would be another factor related to medication adherence. Studies showed that adherence was 85% when participants took two daily doses, but dropped to 67% when taking four daily doses (Kruse, Eggert-Kruse, Rampmaier, Runnebaum, & Weber, 1991). It is much easier for patient to follow the simper medication regimens because of reduced cognitive demands and fewer side effects.

Improving Adherence

Clearly, medication adherence is influenced by many factors. Taking medication as prescribed involves individuals' cognitive resources and system factors as discussed above. Medication adherence cannot be predicted just by a single factor. Therefore, approaches to improving adherence are likely to be more successful if they address multiple factors.

One way to improve medication adherence is to have interventions during the clinic visit. Previous research has shown that successful communication between patients and providers have strong influence on medication adherence (Stewart, 1995). Ideally, during the visit, patient-provider communication should mitigate the deficiency and cognitive demands of patients we discussed above. The provider should present information that patients need for adherence, and check patients' comprehension about illness, drug usage, links between them and discuss and implement adherence plan. But because of system barriers such as limited time for each visit and inadequate communication training, such patient-centered communication, is rarely achieved (Bodenheimer, Lorig, Holman, & Grumbach, 2002). For example, when prescribing new medications, providers omit the medication information that patients need, present disorganized and dense information, or do not assess patients' understanding of the information that is presented. Inadequate communication between patients and providers reduces patients' understanding of the disease, benefits and risks of treatment, and proper use of medications, which contributes to poor health outcomes (Schillinger et al., 2003; Tarn, Heritage, Paterniti, Hays, Kravitz, & Wenger, 2006). Also, failure of the patient and provider to agree on a plan for taking medication leads to negative health outcomes (Machtinger, Wang, Chen, Rodriguez, Wu, & Schillinger, 2007).

Lots of literature reviews has discussed this issue and called for improving the quality of communications between patients and providers across all ages (Vermeire, et al., 2001). Traditional ways to measure the communication depends on patients' ability to recall doctors' instructions. Although some studies (e.g. HIV patients) indicated that quality of communications between patient/provider interactions predict medication adherence behaviors (Barfod, Hecht, Rubow, & Gerstoft, 2006), others(e.g. African-American patients) show the opposite results (Kressin, Wang, Long, Bokhour, Orner, Rothendler, et al, 2007).

Clearly, communication can influence adherence, but the processes underlying this relationship are still unclear.

Patient and provider communication is usually inadequate for multiple reasons. First, providers only have limited time to interact with patients, thus failing to check patients' comprehension about medication (Apsden et al., 2007). In one study, providers overestimated patients' health literacy and thus failed to assess patients' understanding (Bass III, Wilson, Griffith, & Barnett, 2002). Therefore, providers may fail to perceive that patients have literacy problems and to assess patients' literacy ability, resultingin poor communication. For example, they may still use medical jargon without realizing patients' inability to understand the contents and fail to develop a shared adherence or treatment plan, thus leading to bad health outcomes.

Communication style is also influenced by patients' socioeconomic status. (Willems, De Maesschalck, Deveugele, Derese, & De Maeseneer, 2005). Patients with lower socioeconomic status often receive less positive utterances and the style of communication is more directive with less input from patients. Such patients may be unable to be engaged with doctors and to build an interactive dialogue with providers. This may especially be the case for patients with limited literacy.

2.2 Patient-Provider Collaboration, Distributed Cognition & External Aids

Clearly, communication between patients and providers plays an important role in influencing medication adherence in the current health system. Poor communication can influence patients' medication adherence which would possibly lead to preventable adverse drug events. Before discussing any intervention to help communication and thus improve adherence, it is important to understand the nature of collaboration. After analyzing collaboration, I will consider possible benefits of external aids for collaboration.

Communication and Collaboration

Clark (1996) has introduced three key concepts about communication. First, communication is the key to the transformation of each individual into a collaborative unit because communication is a joint activity, in which individual participatory actions are coordinated. This joint activity is not merely the exchange of information. It also involves producing utterances to contribute to the conversation, hearing and understanding the information to reach the mutual understanding and knowledge of situations. Second, the grounding process in communication is essential to building the mutual understanding between communication partners. During collaboration, common ground should be appropriately updated whenever the conversation is carried forward by mutual signaling and checking. Third, during face-to-face conversation, more implicit, non-linguistic information was involved such as gestures, eye gaze and facial expression. These could assist people to communicate and coordinate the dialogue.

Clark and Brennan (1991) also distinguished two types of coordination, the content and the process. The former involved the sharing understanding and rules of the task such as medication information and constraints and patient's daily routine. The latter required the grounded content and a continual updating of common ground. Take the medication scheduling task as an example, patients hold the information about their daily routine while providers are experts about medication information. At the beginning, both of them need to exchange the information to build the common ground, so that the information is mutual understanding. When discussing the medication schedule, either patient or provider will present the medication schedule and the other party would agree or disagree with the proposal. Whenever new information is added or wrong information is corrected, their common ground will be continually updated, and finally reach mutually agreement and understanding about medication schedule. This process is central to collaborative planning and communication between patients and providers.

Such a long process of collaboration could easily break down. First, one party could misunderstand the information and then fail to adequately update his mental model of the current situation (Morrow, Rodvold, & Lee, 1994). Second, if the other party fails to give adequate feedback, both parties' mental model will mismatch. If the misunderstood is not corrected in a timely manner, the frustration would increase, which may lead to adverse events or other undesirable outcomes.

Also, even good communication and collaboration between patients and providers doesn't guarantee the best outcomes. The process of collaboration and characteristic of individuals would moderate medication scheduling tasks performance. Previous study showed, compared with individuals, the collaboration by dyads didn't produce distinctive cognitive products (performance) attributable to group works (Hill, 1982). In other words, groups do not always perform as well as individuals, in part because individuals' limited cognitive resources can undermine collaboration. One way to improve group performance is to provide external aids that reduce the cognitive demands of collaboration. Patients and providers had different cognitive abilities in working memory, knowledge of domain and literacy which might undermine grounding process. Their processes of collaboration became incomplete. As a result, in order to help the process of collaboration produce better outcomes and more productive, the external aids for collaboration is needed.

External Aids Support Collaboration

As distributed cognition theory suggested (Hutchins, 1995), cognition is often distributed among collaborative partners and participants' internal and external representations. The external representations provide ready access to task information and reduce individuals' working memory load, which can assist individuals to do complex tasks. With the help of external tools, the operators can focus on the understanding different sources information and integrate them to make correct decisions or plans without retaining the information in their memory. Distributed cognition theory emphasizes the importance of collaboration between individuals and external tools under complex situations. For medication scheduling tasks, patients contribute information about their daily routine while providers are expert in medication and health information. Both parties need to share thus information to create effective plans. Without external aids, both parties need to understand and remember each other's information and collaboratively discuss possible plans. The discussions and topics could go back and forth and both finally settle down the plan and come to the agreement. This collaboration would easily fail during the process and undermine planning because of limited cognitive resources.

External aids can support collaboration between patients and providers in multiple ways. First, external aids can help patients and providers ground key information and put patients and providers on the same page (Clark & Brennan, 1991). For example, external aids can present medication information or details of patients' routine and both patients and providers can easily share their mutual knowledge and assumptions at less cost to their cognitive resources. By presenting the necessary information on the tool, the communications between patients and providers can be easily transformed into a collaborative unit as Clark suggested. Second, the communication might become more effective because patients and providers can easily share the information and have more interactions with each other (Convertino, 2008). Also, both parties can even use implicit cues such as eye gaze and gestures to interact with each other. Third, the common ground will be continually updated whenever there is any change of current status. Even when miscommunication happened, the external aid provided the visual cues of current status. Patients and providers can easily pick up or correct the mistakes. Also, the external aids will help providers check patients' comprehension as well. Fourth, as common ground develops, patients and providers collaboratively developed medication schedule. Patients were engaged in developing their own schedules and their considerations and limits were taken into account. The result was that patients would be more likely to adhere to the medication schedules.

External Aids Support Problem Solving

External aids can assist our cognitive functions in multiple ways. One way to present the external aids is by external representations such as diagrams. Larkin & Simons (1987) have found that diagrams can lower the cognitive demands by supporting perceptual inferences. Also, external aids can also present the task relevant information. Users have less for information search, retrieval or maintenance in working memory (Zhang & Norman, 1994).

Problem solving often requires planning processes such as formulating a method for attaining a desired goal state. External aids also help participants to develop strategies to tackle problems. Cary and Carlson (1999) found that participants would strategically develop and arrange subgoals to achieve overall goals to solve particular problems. Moreover, strategies participants developed would correspond to the conceptual structure of the problem which help participants to learn to solve the problem more quickly. However, their adopted problem-solving strategies would be influenced by other factors:

the availability of an external aid, the availability and nature of the problem, and the continuing availability of information displays.

External aids could also help participants to solve problems more easily. Roschelle and Teasley (1991) asked students to use a computerized aid (envision machines) to collaboratively learn and solve physics questions. They found that this external aid could serve as a mean of disambiguating problems. Students used the shared diagrams in the external aid as a mean for establishing shared reference. They also used the external aid as means of resolving impasses. They would try out their ideas on the external aid to see whether it would work or not. As a result, visualization of problems is a key factor to problem solving process.

Information Display in Problem Solving

As mentioned previously, external aids could help people to solve problems in different ways. Some research has shown that information displayed in graphs and tables enhanced performance for tasks requiring data interpolation and the reading for specific values (Carter, 1947; 1948a; 1948b). It is less clear how to display information to support collaborative problem solving in complex real life problems., For example, medication scheduling problems not only requires patients and providers to understand information, but to consider other conditions (patients' routines, take as few times as possible) and constraints (medication conflicts) at the same time. When solving this problem, which information do they need to consider first? As a result, external tools needed to be designed that fit peoples' mental model of medication taking to assist them to solve problems.

Prioritizing constraints is an important factor in solving medication scheduling problems. Although only few studies have discussed medication constraints, similar types of problems were found in other fields: the diagram construction task. The diagram construction task is used by architects and the goal of this task is to satisfy multiple, sometimes conflicting constraints, to achieve an acceptable design for clients. Katz (1994) found that professional architects' initial designs were more consistent with task constraints and their draft would remain more consistent (less significant changes of their design) throughout the process compared to students. Moreover, professionals' superior performance is their early recognition of critical constraints. They would properly order the different constraints and minimize constraints conflicts.

Current Study

The overall goal of the present research is to understand how patients and providers collaboratively solve medication scheduling problems in a simulated patient-provider interaction and the impact of different orders of information display on problem solving strategies. As a first step, the data collected from the Waicekauskas (2010) thesis were analyzed to understand older adults' problem solving strategies in medication scheduling problems. The second experiment followed up the results of the Waicekauskas (2010) data and was designed to further understand how to help patients and providers' solve medication scheduling problems.

CHAPTER 3: EXPERIMENT I

3.1 Overview of Two Experiments

Two experiments are briefly described and discussed in this section. The first experiment was conducted by Waicekauskas (Waicekauskas, 2010) and the interface interaction data from this study were analyzed by me. The goal of this study was to test whether a computer-based version of the medtable (e-MedTable) assisted patients and providers to develop a medication plan collaboratively in a simulated task that involved older adults who role-played. The tool, e-MedTable, was adapted from the original MedTable (Morrow, et al., 2008) and some changes were made during the development of e-MedTable (See Waicekauskas, 2010). The e-MedTable was personalized to fit each patient's schedule and some features were designed to benefit the elders. If this electronic aid proved successful in helping older adults, who tend to adopt new technology slowly, the finding could be generalized to younger adults who are more familiar with computer technology. And this tool could be used by all ages of users and all computer users. In order to compare effects of the e-MedTable on medication planning to existing paper tools, the original paper medtable and a less structured tool (MedCard) used in actual health care organizations for patient education, were included in the study. The structured aids were predicted to support more effective collaborative medication planning compared to the less structured tool. The e-MedTable was run on the computer and participants were asked to use the computer to collaboratively complete the task. All the mouse clicks and interactions with the e-MedTable were recorded. These data could demonstrate how users interacted with the e-MedTable and how they solved the problems, such as the order in which they considered the medications as they created their medication schedule, or the frequency of revising schedule solutions. Because I was interested in users' interactions with the interface and their strategies to solve the task, I acquired Waicekauskas's permission to analyze this part of the data to include as part of my thesis, which motivated my second experiment.

The second experiment was conducted based on preliminary results from the first experiment. In the first experiment, the patients' interactions with the e-Medtable tool interface were recorded and later coded and analyzed to reveal different strategies involved in planning. The data showed that although participants saw the same order of medication information on the tool (from the top to the bottom), participants differed in which medication they started with when they created their schedule. That is, some participants used the order suggested by the tool and others used other orders. As a result, I am interested in those who took different orders to solve the problems because these differences may provide insight into how did they solve medication scheduling problems. Participants could use a more global approach in which they started the problem by viewing constraints across medications before beginning to create the schedule. It would be more likely that they started the conversation about which medication should be scheduled first which will make the problem solving process easier without revising schedules later on. This would encourage the self-initiated strategy.

From the first experiment, we only presented four medications in one order, so we couldn't identify whether each problem itself did invite participants to create the schedule in a particular way or not. Also, did the use of different orders to create the schedule influence problem solving performance? It was possible that they chose to take different orders to solve problems because it could simplify the process to create the medication schedules and they could invest less cognitive effort to solve the problems. For example, participants could start with the most constrained medications because the solutions to this medication had less available spots on the schedule, so later on when they continued to schedule the rest of medications, they didn't need to change the schedule for the most constrained medication. They could easily change the schedule for the less constrained medications. This would streamline the medication scheduling process without iterations. As a result, I was interested in how people created the medication schedules when the medications were presented in a particular order on the tool (did they follow the suggested order or not). The aim of the second study was to better understand the effect of different orders of medication information on medication scheduling tasks. If the information was presented in different orders, would their strategies to solve the task (that is, create the medication schedule) also change In the present chapter I describe how I analyzed the mouse click data from Waicekauskas (2010), the results of these analyses, and limitations of these findings. in Chapter 4 I describe the follow-up experiment designed to clarify the role of medication order on collaborative problem solving.

3.2 Participants

As reported in Waicekauskas (2010), 144 older adults participated in this study and were recruited from the local community. All the participants were 60 years and older (age: M = 71, SD = 7.3). Ninety-two participants were female (64%). Participants were paired and randomly assigned to the role of patient and provider. Pairs were also randomly assigned to one of the three types of tool groups (Medcard, MedTable and e-MedTable; 24 pairs per group). . Participants were screened to meet several criteria. All participants were native English speakers, had no obvious physical or cognitive disability (e.g. stroke in the last three years, having chemotherapy or radiation) and were not health care professionals. They also used computers at least weekly, which reduced the chance that participants would have significant difficulty using the e_Medtable tool. There were no significant differences in age, education and verbal ability among three groups.

3.3 Procedure

This was a simulated patient-provider experiment (see Morrow et al., 2008). Older adults participated in this experiment in pairs. After obtaining their consent, they first filled out the demographic survey and completed the Advanced Vocabulary test, a measure of verbal ability (Ekstrom, et al., 1976). Then they were led to the experiment room. At this time, they were randomly assigned to the patient and provider role, and the pair was randomly assigned to use MedCard, Medtable or e-MedTable tool. The patient was given the patient routine information, including daily event times (wake-up breakfast, lunch, dinner and bedtime) and work schedules. The provider was given the prescribed medication information, which included not only how to take the medications, but why the patient needed to take these medications. Neither the patient’s work schedule nor the provider’s reasons about why the patient needed to take the medication were on the tool. This information was included to encourage both participants to be involved in the tasks and to work together to create the medication schedules. Before the task started, participants were given one minute to read and become familiar with the material, and then they worked out the patient's medication schedule plan together and had 15 minutes to complete the task. Task completion time was measured by a stopwatch. The patient was in charge of documenting the schedule on the tool.

All participants first completed two sample problems in the same order (one simple and one complex) in order to become familiar with the scheduling task and the tool. Before each problem, participants were told that schedules with fewer medication times are generally better because they are easier to remember and follow (Osterberg & Blaschke, 2005). Then four problems (two simple and two complex) were given to participants and the problems were blocked by complexity, with order of blocks counterbalanced across participants. Whenever participants indicated they completed the task, the experimenter would stop the stopwatch. The experimenter would ask the patient to read back their medication schedule plan. The purpose of the read-back was to check patient's understanding about his medication schedule plan and if participants found out any mistake, they could revise the schedule again. Any time needed to revise the schedule was added to the task completion time. After the read-back, both the patient and provider were given the NASA-TLX to complete.

After all the problems were completed, only the patient completed the Tool Usability Survey which was developed from the ten questions of the System Usability Scale (SUS) (Brooke, 1996) because only the patient used the tool. Then both participants were given the Partner Awareness survey to fill out their perceived collaboration during the task. This survey was derived from the Activity Awareness Questionnaire (Convertino, Mentis, Rosson, Slavkovic, & Carroll, 2008). After the medication problems were completed, participants were asked to do the Letter and Comparison Tests (Salthouse, 1991b) All the measures mentioned above would be discussed more in the 3.6 dependent variables and cognitive ability measures.

3.4 Interface: e-MedTable

The e-MedTable was used in both studies to support communication and collaborative medication scheduling. The current version of the e-MedTable was developed by Kevin Waicekauskas for his masters thesis (Waicekauskas, 2010). The intent was to preserve the layout and functionality of the paper-based MedTable (Morrow, et al., 2008). This interface included medication information and patients' 16- hour daily routine. The medication information contained detailed instructions about how to take the medication. Patients and providers used the medication information and daily routines to create their medication schedules. The intent of e-MedTable was to support patients and providers' collaborative scheduling. They could create the schedule and edit the current schedule to reach their optimal solutions.

The e-Medtable was developed in Microsoft Access 2007 with Visual Basic for Application. Figure 1 (Waicekauskas, 2010) shows that the interface had 6 components: (1) Box A contained the medication instructions, including number of pills per time, number of doses per day, when to take or not take, what should eat or not eat while taking medications and some medications couldn't be taken with specific medication (medication conflict). Also, (2) Box B was a drag down menu. Patients first clicked the menu and the names of four medications were shown in the same order as the top-bottom arrangement of medications in Box A. Patients could decide which medication they wanted to work on. (3) Box C contained pictorial icons representing the patient's daily routine: events such as breakfast, meal time and bedtime which could enhance patients' prospective memory. As Mayer & Moreno (2003) suggested, appropriate pictorial pictures could help patients comprehend depicted concepts and associate medication taking times to daily events, which will reinforce their prospective memory. (4) Box D contained 16 time buttons for each hour of the patient's day. Whenever patients decided to take pills at a specific time, they needed to click the time button indicating the corresponding hour. After patients clicked, the program would mark a check on the time button and automatically populate the corresponding cell in the table (Box E) with x's. The number of x's represented the dose, or numbers of pills, to be taken at that time. (5) Box E was the medication scheduling table that displays the patient's routine and medication names, and the medication schedule as it is built. The table contained 64 cells (4 medications x 16 hours per day) and each cell represented one hour for one medication. If the patient decided to change the time of the medication, he or she needed to go back to the medication to be changed by dragging down combo-box and click the time button again. The check on the time button and x's on the cell would be erased. (6) Box F contained the administrative buttons. After finishing the task, the patient clicked the "Save" button to save their completed medication schedule. The "Reset" button was used when they want to clear the medication schedule on the table. The "Close/Menu" button quitted the program.

For example, "medication A instruction: take 2 pills twice a day. Take one dose in the morning. Take with meal." Scheduling medication A involved four steps: (1) The patient needed to click the drag down menu in order to select the medication A. (2) After the patient selected the medication A, the interface would be updated: the medication A in the medication information area was highlighted in orange. And the whole row of medication A on the medication scheduling table was also highlighted in light grey (see figure 1). (3) If the patient decided to take one pill in the morning and his breakfast time was at 6 A.M., he clicked the time button that above 6 A.M. Then the program would place "xx" in the cell of the medication scheduling table that corresponded to the medication A row and the 6 A.M. column. (4) The second dose wasn't specified when to take. As a result, the patient could take it at any time with routine events. He could choose lunch, dinner or bedtime. Meanwhile, he could also consider taking doses that were evenly spaced throughout the day because drugs work best when the amount of medicine in the body were kept constant. So if the patient decided to take one pill at dinner time, he would click the time button that was above 6 p.m.. Then the program would automatically populate the cell of the table with 2 X's corresponding to 6 p.m. If the patient wanted to change the schedule, he could click the time button just clicked before to cancel the schedule. After he finished this medication A, he could continue to create schedules for other medications by clicking the drag down menu to choose another medication.

As the distributed cognition framework (Hutchins, 1995) suggests, external aids can help collaborators exchange the information and build up common ground (shared knowledge relevant to task). Also, external aids could present needed information for the task, reducing working memory load of the schedule task. For example, because the medication and patients' routine information are presented on the tool directly, the patient doesn't need to remember the medication instructions. Similarly, the provider doesn't need to remember the patients' schedule every time they discuss it because it is visible. To summarize, patients and providers shared visual cues that could facilitate their conversation and the planning task.

Figures and Tables

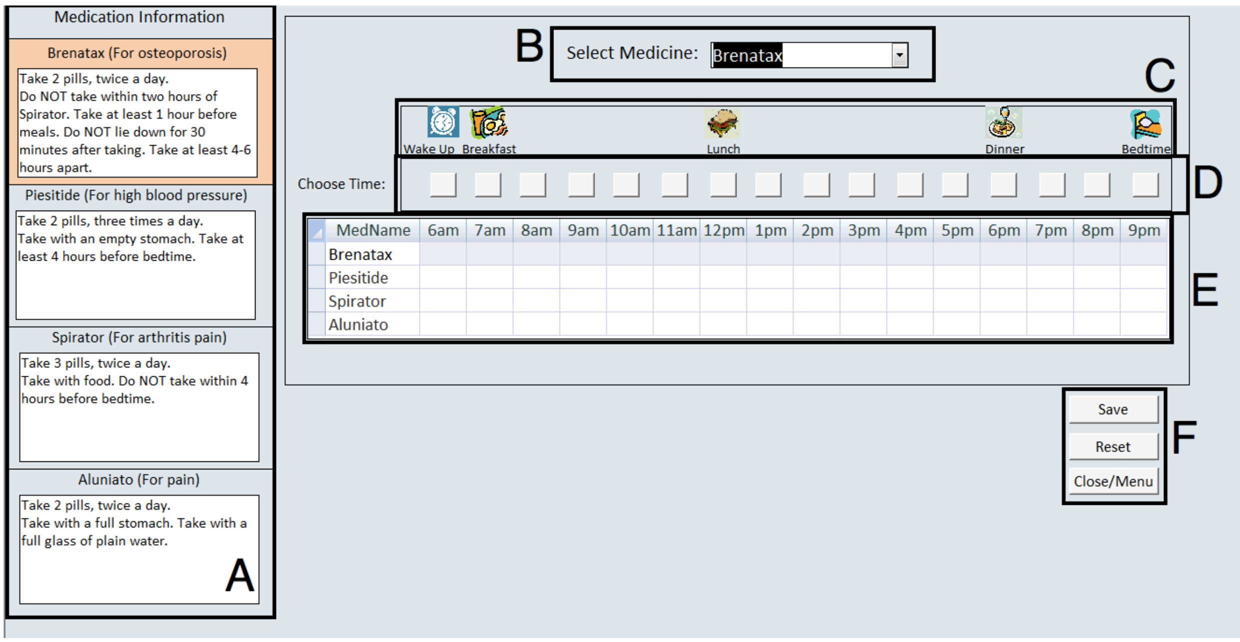

Figure 1. The e-MedTable with highlighted components: A) the medication information boxes, B) the select medicine combo-box, C) icons representing the patient's daily routine, D) buttons for scheduling a medicine taking time, E) the medication scheduling table, and F) administrative buttons.

3.5 Medication Scheduling Problems

Participants completed simple and complex medication scheduling problems that were created by the research team. Each medication scheduling problem included four medications. Information for each medication included name, the purpose of this medication, number of pills per dose, number of doses per day and instructions (e.g. take with meals, take with empty stomach). There were two practice problems (one simple and one complex), and four experimental problems (two simple and two complex). All the medications were fictional but realistic, with medication instructions and names created from existing online database of medication (www.rxlist.com). Each problem also included a rigid patient routine. Their wake-up time, breakfast, lunch, dinner, bedtime and work schedule including breaks were at fixed times. The work schedule was not shown on the tool and only the participants serving as patients were given this information (on a sheet of paper). The daily routine spanned 16 hours per day, and the time of daily events varied across problems. While figuring out the medication schedules, participants were told that the patient's schedule was not flexible. They were asked to figure out the optimal schedules given the information we assigned to them. The intention of the rigid routine was to simplify medication problems and maintain the consistency of each problem that participants received.

Problem complexity was defined in terms of the size of the possible solution space (Morrow et al., 2008). The complex problems had more constraints on when medications could be scheduled; so that, there were fewer feasible slots that patients could choose to meet the criteria. Also, the complex problems involved the co-occurrence of constraints between medications (e.g. med A cannot be taken within two hours of med B). In other words, participants needed to devote more cognitive effort to the problems because there were more conditions they needed to consider.

3.6 Dependent Variables and Cognitive Ability Measures

Dependent Variables

Problem-solving (the medication schedule task) performance was measured by three dependent variables: (1) Solution completion time and accuracy, (2) subjective workload (NASA-TLX; Hart, 1988), and (3) interface interaction. The interface interaction was recorded by the Morae software (TechSmith; www.techsmith.com/morae.aps). The results of problem solving performance and workload in the study I are reported in Waicekauskas's thesis. Only the interface interaction data are analyzed and described here. However, the he problem solving and workload measures are described in some detail here because study II uses the same task and measures.

I. **Problem solving performance**

Solution completion time. Solution time was measured (in seconds) from when participants started to use the tool to do the medication scheduling problem until they told to the experimenter that they had finished the problem. A maximum solution time limit of 15 minutes was imposed for study I. After participants declared they completed the task, they were asked to read-back their medication scheduling plan. During the read-back, if they wanted to revise the medication schedule, the surplus time was added into solution time.

Solution accuracy. Solution accuracy was calculated for each problem from the participants' verbal readback of the schedule and defined as the proportion of problem constraints met by the solution. These constraints included: medication was scheduled, correct number of doses per day, appropriate medication taking times, patient's daily routine constraints, and medication co-occurrence constraints (Waicekauskas, 2010). For example, "Take 2 pills twice a day. Take at least 1 hour before the meal. Take one dose in the morning."

We will ask the following questions when scoring the data:

1) Was this medication scheduled?
2) Was this medication described as taken twice a day in the schedule?
3) Was the first dose was taken at least 1 hour before the meal?
4) Was the second dose was taken at least 1 hour before the meal?
5) Was one dose was taken during the morning?

If each question was met by the solution, 1 will be recorded for that question; otherwise 0.

II. **Workload**

The NASA-TLX assessed six factors of subjective workload associated the developing the schedules, including mental demand, physical demand, temporal demand, self-appraised performance, effort and frustration on 100-point scale (Hart & Stavenland, 1988). Participants marked their subjective perception of each factor on the scale for each task, from very low to very high (except the self-appraised performance from perfect to failure). Smaller scores on each scale represent lower workload perceived performance as perfect.

III. Interface Interaction

As mentioned earlier, the software, Morae, recorded how participants interacted with the interface, including the mouse clicks (including time and location of each click) and discussion between the patient and provider for all tasks. The patterns of mouse clicks behaviors in each problem could provide more details about how participants solved the medication scheduling problems. For example, the pattern of mouse clicks could tell us which medication this pair tried to solve first, which medication they needed to edit several times, how much time they spent on each medication and the orders of four medications they took. Although Morrow et al. (2008) and Waicekauskas (2010) have shown that the MedTable/ e-MedTable tools supported better problem-solving accuracy compared to unstructured paper tools, the process data provided by Morae can shed light on how participants perform the task, such as reconciling patient's medication information and daily routine schedules.

To have a consistent and thorough understanding about the pattern of mouse clicks, our group developed a coding scheme to mark each click. The Morae program allowed the experimenter to set the marker for each click to have a quick understanding about what was happening and when users took actions on the interface. Each click was coded based on locations of clicks and sequences of clicks. As a result, with the timestamps and coding scheme, we were able to identify which medication participants started to schedule, the order of scheduling the four medications, as well as the total trial time and number of times they revised for each medication.

This coding scheme included several categories: (1) Combo-box: the patient would click the drag down menu when they decided to change the medication they wanted to work on. (2) Select medication: the patient chose the medication that they would like to work on. This coding also indicated which medication they were going to work on. As a result, four medications were coded separately in each problem. (3) Check medication: the patient decided to choose the time slot and click the time button. (4) Uncheck medication: the patient decided to delete the time he chose before. (5) Reselect medication: the patient has already scheduled this medication before and he decided to change the medication schedule again. In other words, if the patient clicked the drag down menu and selected one medication more than once, this click would be coded reselect medication. (6) Error: when the patient clicked invalid places on the tool interface and these kinds of error clicks were not related to problem solving process. Participants were shown the invalid clicks (no effect on the interface) during the training sessions. There were three types of errors, corresponding to three different places patients might click: medication information (figure 1, box A), table (figure 1, box D) and any other place. Theses error clicks could demonstrate users' confusion about how to interact with the interface. This could imply users' incorrect model of interacting with the interface. Based on different types of error clicks, patients' difficulty with the e-MedTable was revealed. For example, if patients made specific errors more frequently than others, this would imply some usability issues of the interface. An analysis of these error clicks was reported in Waicekauskas's thesis. (7) Administration: the patient would click the save button to indicate they completed the task.

Based on this scheme, an analysis of the time and marks of each click provided preliminary information about: the order in which participants scheduled the four medications, the time spent per medication while scheduling, and the number of times they revised each medication.

Order of four medications. Identifying the order in which participants scheduled the four medications was important in order to understand how they solved the problem. Patients and providers were presented the four medications in one order, from the top to the bottom of the display (tool order). On the interface, participants could either start from the first (top) medication and follow the order on the tool (tool order strategy) or they could initiate their own order to solve the problem (self-initiated order strategy). We were interested in why they might use these two strategies in creating their medication schedule.

Take the four medications in Figure 1 as an example. The tool order from top to bottom on the interface was: Brenatax (the first medication, called med 1), Plesitide (med 2), Spirator (med 3) and Aluniato (med 4). Participants could either follow this order or chose their own (self-initiated) order, such as the following:. Brenatax (med 1 on the display), Spirator (med 3 on the display), Plesitide (med 2) and Aluniato (med 4) or they might start with Spirator (med 3 on the display), Plesitide (med 2), Aluniato (med 4) and Brenatax (med 1).

To complicate the situation further, participants sometimes used different medication orders before completing the schedule. For example, during the scheduling process, participants might need to change a previously scheduled medication if they found the chosen medication time conflicted with a later medication time, or if they wanted to make the schedule more optimal. As a result, they went back to the already scheduled medication and reselected the medication on the interface and clicked the time button to change the schedule. This situation was defined as revision. Each problem could involve several revisions for each medication and the orders of four medications would be more varied. To simplify the situation, the revisions were ignored when it comes to orders of four medications. For example, med 1, med 2, med 1, med 2, med 3, and med 4. In this situation, we counted it as following the tool order (med 1, med 2, med 3 and med 4) because the intention of participants was to start the first medication, the second medication, the third medication and then the fourth medication. Because they needed to reconcile all medication schedules, some revisions were made to meet the constraints of medications. Another example: med 2, med 1, med 2, med 1, med 3 and med 4. This situation was counted as the self-initiated order (med 2, med 1, med 3, med 4) because participants started directly from the second medication on the interface, went back to the first medication and then finished the rest.

Before participants started to use the e-MedTable to solve the problem, the first medication was automatically chosen by the program already. Then participants either started to schedule the first medication or selected another medication to start from and started to schedule that medication. However, in the data, we found that participants sometimes would click the combo-box and select the medication but would not schedule the medication or revise the original medication plan (click any time button). Then they directly selected another medication. Participants did this because they accidentally selected the wrong medication they wanted to schedule or they just selected the medication without making any change or they found medication schedules they had made had conflicted with next one they wanted to plan. They needed to go back to revise the previous medication schedules to create the schedules that met all the constraints of medications. However, this was an ambiguous action and we could not determine the intentions of users based on the interface interaction data (17.13% in complex problems; 6.0 % in simple problems). As a result, we didn't include this situation in the data of orders of medication in order to reduce the noise in the data.

A limitation of the findings in this experiment (and conclusions about the reasons for adopting strategies) is that the four medications in each problem were always presented in the same order, so that type of medication and presentation was confounded. This issue is addressed in Experiment 2 of the thesis (Chapter 4).

Ability Measures

Participants also completed two surveys and several tests that measured their cognitive abilities. Cognitive abilities that might influence participants' problem solving ability, as well as their ability to effectively use the tool interfaces to solve the problems were measured. The demographic survey asked participants' sex, education, occupation, computer usage, self-assessed health score and medication they were taking. Verbal ability was measured by the Advanced Vocabulary Test (Ekstrom, French, & Harman, 1976) from the ETS Kit of Factor-Referenced Cognitive Tests. Speed of mental processing was measured by two tasks, Letter Comparison and Pattern Comparison (Salthouse, 1991b). These two tasks were comparison tasks and participants were given 30 seconds to compared whether pairs of letters or patterns were the same or different as fast as they could. Speed of processing is considered a "fluid mental ability" that is important for predicting efficient information processing.

3.7 Results

Order of Scheduling the Medications

Tool Order vs. Self-initiated Order. The four medication scheduling problems were analyzed separately rather than collapsing over types of problems (simple vs. complex) because medication constraints differed for each problem, which might influence whether people followed the tool order or they self-initiated a different order. Overall, about 37.1% of pairs of participants followed self-initiated order. Table 1 summarizes the percentage of pairs following the tool order for each problem. The table shows that two thirds or more of participants followed the tool order for each problem (83.33% for S2, 66.67% for S3 and 70.83% for C2) except problem C3 (36.1%). The binomial test was conducted to test whether following the tool order or following a self-initiated order was equally likely to happen (H_0 = 0.5). The result indicated that participants were more likely to follow the tool order for problem S2 (p = .002), with a marginally significant difference (p = .064) for problem C2.

As we mentioned earlier, most participants followed the tool order except for problem C3. Cochran's Q test was conducted to test whether the distributions of following the tool order and self-initiated order were different across different problems. The results showed that the distribution of following the tool order of C3 was significantly different from those of other problems (df = 3; *p* = .001). Even when the data were collapsed by problem complexity, the result from NcMemar Test still indicated that the distribution of following the tool order in the simple problems was significantly different from the complex problems (df = 1; *p* = .021).

Order of Medication Scheduling the Medications in the Self-initiated Orders. After coding the order of four medications, the order in which the medications were scheduled when participants did not follow the tool order was next analyzed. Table 2 shows that this analysis did not reveal a consistent preference for starting with a particular medication to schedule the medications.

Number of Schedule Revisions. As mentioned earlier, the number of revisions (number of times medications were rescheduled) when developing the schedule was counted based on the orders of four medications and calculated number of times each medication was scheduled in each problem. If participants appropriately solved the problem, each medication should be selected and scheduled at least once. As a result, the number of times each medication was visited by each pair in each problem subtracted by 1 was equal to the number of revisions for each medication in each problem. However, not every medication would be visited twice and many participant pairs completed the task without any revision. Table 3 shows the results of the mean number of revisions by problem.

The nonparametric Kendall's W test was used to understand whether tool versus self-initiated order strategies were related to number of revisions in different types of problems. The result showed that for the simple problems, types of order were significantly correlated with number of revisions (df = 1, X^2 = 18.778, p = .001); that is, there were fewer revisions when participants followed the tool order. For the complex problem, types of order were not significantly correlated to number of revisions (df = 1, X2 =2.0, p = .157). This latter result may reflect the large standard deviation in the complex problems.

Number of Revisions for Each Medication. Another way to explore these data was to compare the number of revisions for each medication by problem because each medication had different constraints, which might influence difficulty of integrating the medication into the schedule (table 4). Based on the order of four medications on the interface (tool order) in each problem, the number of revisions for each medication was counted. If one specific medication was revised more times compared to other medications, this would imply that participants were more likely to have problems with this medication. The more revisions made for the medication, the more difficult that medication was. The result revealed that the first medication and the second medication in the complex problem 2 had the highest frequency, 20 and 10 respectively.

From the medication scheduling problems (Appendix A), the first medication and second medication in complex problem C2 were Previum and Spirotar, respectively. Consider the associated information for each medication. Previum: "Take 1 pill three times a day. Do NOT take any other medication within 1 hour. Take at least 1 hour before or 2 hours after a meal." Spirotar: "Take 2 pills twice a day. Do NOT take within 4 hours of bedtime. Do NOT take within 2 hours of taking Previum". It was apparent that the Previum and Spirotar had time conflict with each other and Previum even couldn't be taken with the other three medications. Participants couldn't schedule Previum at the same time slot with other medications and Previum and Spirator should be taken at least two hours apart. If participants followed the tool order to solve the problem and didn't consider the second medication (Spirator) at the same time, it was very likely that they would need to go back to the first medication (Previum). As a result, we split the data into the tool order strategy and self-initiated order strategy (Table 5).

Table 5 summarizes the mean of number of revisions for each medication by tool order and self-initiated strategy. The descriptive statistics results indicate that pairs who used the tool order strategy revised the first medication about 0.87 times, while pairs who used a self-initiated order strategy revised the first medication about 0.43 times. Other medications didn't show significant differences or have comparatively large mean of number of revisions.

Total Solution Time. Participants used e-MedTable spent more time on complex problems ($M = 509$) compared to simple problems ($M = 242$), (t (18) = -7.293, $p < .00$; M) (See Waicekauskas, 2010). The problem solution time could also be averaged by types of problem (complex and simple), and compared for groups who followed the tool order and for those who took self-initiated order (table 6). Kendall's W test was used to analyze whether the order strategies were related to total solution times in different types of problems. For both simple and complex problems, order strategy was highly correlated with total solution time ($df = 1$, $X2 = 48$, $p = .00$; $df = 1$, $X2 = 47$, $p = .00$ respectively). The mean trial time was significantly longer in the self-initiated order than in the tool order even though there were fewer revisions.

Impact of Self-initiated and Tool Order on Problem Solving Performances

It remains unclear why some pairs chose a self-initiated order for scheduling rather than the order suggested by the tool. In the present section I describe the results about the effect of self-initiated orders on solution completion time, number of revisions and accuracy. The dependent variables were solution completion time, number of revisions and accuracy. The independent variable was whether participants followed the tool order or not. The tool order group and self-initiated group were coded 1 and 0 respectively. To understand the impact of taking self-initiating rather than following the order suggested by the tool, the data were collapsed over problems. 96 samples (24 pairs X 4 problems) were analyzed. ANOVA was not appropriate because of the lack of independence in the data.

Therefore, generalized estimating equations (GEEs) was used in order to handle the correlated observations.

Order Strategy and Solution Completion Time. For the best fit of GEEs model, unstructured working correlation matrix was used with Gamma log link function (QIC = 31.67; QICC = 31.44). There was a marginally significant difference (df = 1, $X^2 = 3.703$, $p = .054$) between following the tool order (M = 344.8) and self-initiated orders (M = 428.26), with participants taking longer when using self-initiated orders.

Order Strategy and Number of Revisions. For the best fit of GEEs model, unstructured working correlation matrix was used with negative binomial log link function (QIC = 107.03; QICC = 106.27). The number of revisions did not differ (df = 1, $X^2 = 0.724$, $p = .395$) when participants followed the tool order (M = 0.89) and used self-initiated orders (M = 0.54).

Order Strategy and Schedule Accuracy. For the best fit of GEEs model, unstructured working correlation matrix was used with Gamma log link function (QIC = 4.386; QICC = 4.2). Accuracy did not differ (df = 1, $X^2 = 0.006$ $p = .938$) when participants followed the tool order (M = 97.64%) and used self-initiated orders (M = 97.56%).

Figures and Tables

Table 1. Percentage of pairs following the tool order and self-initiated order when scheduling medications for each problem. The asterisk indicated the statistical significance: p < .05 (**) and p < .1 (*). Four problems were used: two simple (S2 and S3) and two complex problems (C2 and C3).

	S2**	S3	C2*	C3
% of following tool order	83.33 %	66.67 %	70.83%	36.1%
% of following self-initiated order	17.67 %	33.33 %	29.17%	63.9%
Mean percentage of following alternative order	25.5%		46.54%	

Table 2. Number of times the medication they started from for self-initiated order group. Four problems were used: two simple (S2 and S3) and two complex (C2, C3) problems.

	Simple problems		Complex problems	
	S2	**S3**	**C2**	**C3**
med 1	1	0	0	5
med 2	1	5	3	2
med 3	2	3	0	3
med 4	0	0	4	5

Table 3. Means of number of revisions by problem and order type (order in which participants scheduled the medications: tool order and self-initiated order). N = number of pairs in each condition.

Problem	**Simple**		**Complex**	
Types of Order	**Tool Order**	**Self-initiated Order**	**Tool Order**	**Self-initiated Order**
N	36	12	25	22
%	75%	25%	53%	47%
Mean	0.24	0.33	1.52	0.68
SD	0.65	0.65	1.96	0.89

Table 4. Number of revisions for each medication in each problem. Four problems were used: two simple (S2 and S3) and two complex (C2, C3) problems.

	S2	**S3**	**C2**	**C3**
First medication	1	1	19	3
Second Medication	0	4	10	4
Third Medication	1	1	7	2
Fourth Medication	2	2	6	2

Table 5. Mean of number of revisions for each medication in each problem. Four problems were used: two simple (S2 and S3) and two complex (C2, C3) problems.

Problem	S2		S3		C2		C3	
Type of Order	Tool	Self-initiated	Tool	Self-initiated	Tool	Self-initiated	Tool	Self-initiated
1st medication	0	0.25	0.06	0	0.94	0.43	0.13	0.13
2nd Medication	0	0	0.19	0.13	0.41	0.43	0.25	0.13
3rd Medication	0.05	0	0.06	0.00	0.35	0.14	0.13	0.07
4th Medication	0.10	0	0.06	0.13	0.29	0.14	0.00	0.13

Table 6. Means and standard deviation of total trial time (seconds) by problems and solution order strategy. Four problems were used: two simple (S2 and S3) and two complex (C2, C3) problems.

	S2		S3		C2		C3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tool Order	203.44	91.34	203.44	93.18	544.59	233.14	398.63	170.30
Self-initiated Order	306.75	91.09	253.25	70.54	604.14	275.10	471.93	174.52

3.8 Discussion

About 36% of pairs initiated their own order to create the medication schedules. When looking at the data further by problem, it was clear that the complex problem C3 had the highest percentage of solutions with self-initiated orders (65%) and the simple problem S3 and complex problem C2 had roughly the same percentage of taking the self-initiated orders (33% and 29% respectively). Based on these data, we were interested in why some pairs used different orders to solve the problem. Did this imply any better strategy to create the medication plans? Did this imply the order in which the four medications were presented on the tool influenced how people solved the problem? To try to understand the mechanisms involved in creating the medication schedules, the order of scheduling the four medications when taking a self-initiated order was studied. Unfortunately, there was no evidence that participants used a consistent order of scheduling the four medications when they took self-initiated order. But the results did show that they started the problem with particular medications. For example, in the complex problem C2, those who took self-initiated orders only started from the second medication and the fourth medication. The description of the fourth medication, "Elidone, for thyroid problem. Take 3 pills once a day. Take on am empty stomach.", suggests that this medication didn't have many constraints and therefore had many feasible solutions as long as it was taken on an empty stomach. However, the second medication had more constraints, which limited feasible solutions: "Spirotar, for high blood pressure. Do not take within 4 hours of bedtime. Do not take within 2 hours of take Previum". The Previum medication was the first medication presented in this problem. Moreover, Spirotar cannot be taken within 2 hours of taking Previum. As a result, why did these pairs only start from the second and the fourth medication? These two medications were not presented first on the interface and they contained very different constrains. The second medication was very complex compared to the fourth medication. It is difficult to determine why participants chose one or other medication as the starting point for the problem because the type of medication was confounded with its order of presentation in this experiment.

If using a self-initiated order was a more effective strategy than following the tool order, this strategy difference should be reflected in interface interactions, such as the number of revisions and total solution time. However the number of revisions did not differ for the two strategies. After looking into each problem, the C2 and C3 contained very different medications. If we assumed problem C3 have the same difficulty as problem C2, C3 should have showed large number of revisions too. In complex problem C3, only one medication (Cyltair) couldn't be taken with another medication (Fluxib) (see appendix A) and Cyltair was also the first medication (the top one participants would read) on the interface. Cyltair: "Take 1 pill twice a day. Take with food. Do NOT take with Fluxib." Fluxib: "Take 3 pills once a day. Do NOT lie down up to 1 hour afterwards. Take with food." The only conflict part was that these two medications couldn't schedule at the same time with food. But since both medications were only taken once and you had three meals once a day, it was easier to resolve this problem and participants didn't go back and forth and revise the medication several times. The differences between problem C2 and C3 were different medication constraints in each problem. It was very likely that different medication constraints in each medication and interactions of different medications constraints in different medication indeed influenced the medication scheduling behaviors. The number of revisions was mainly driven by medication-specific information such as medication constraints and medication interactions, not by order in which medications were scheduled. Once again, it was important to examine tool order independently of type of medication, which we did in Experiment 2.

According to Waicekauskas's thesis (2010), complex problems had smaller solution spaces. In other words, complex problems had more constraints that the schedule needed to satisfy (i.e., medication constraints, patient routine), and thus fewer feasible solutions. Participants may have needed to devote more cognitive effort to the complex problems to search feasible solutions and integrate constraints. This may help explain why complex problems had more revisions compared to simple problems, especially in complex problem C2.

As we mentioned earlier, there was a significant effect of complexity on the total trial time (Waicekauskas, 2010). The result of total trial time was divided into two groups: tool order and self-initiated order. The result revealed that self-initiated order group took more time to resolve the problem compared to tool order group but number of revisions self-initiated group took didn't significantly less from tool order group. If self-initiated group took a global approach to review all the medications before solving medication problems, it was more likely that they would solve the medication scheduling problems more efficiently. However, because of high standard deviation, the number of revisions in self-initiated group was not significantly different from that in tool order group. As a result, this couldn't give us insight about whether medication scheduling process will benefit from different types of different strategies.

Although the preliminary data gave us an overview of how participants interacted with the interface, the effect of scheduling orders on medication scheduling problems remained unclear. This may reflect several issues with the design of Experiment 1. First, when the Medtable program was opened, the first medication was automatically chosen. In the current dataset, most of participants just used the first medication as their beginning. We were not sure whether they initiated the task from the first medication by themselves or they just directly followed the information presented to them. In other words, people could minimize cognitive effort needed to solve the problem by following the medication order suggested by the tool. Also, it was possible that participants never thought about starting from another medication. Second, the order of medication wasn't manipulated in this experiment. In the current experiment, the four medications in each problem were arbitrarily ordered. And all the pairs saw the same order of four medications for each problem. If the order of medication on the tool was changed so that order and type of medication would be unconfounded, would participants be more likely to deviate from the medication order on the tool? The second experiment was conducted in order to address these design limitations. We investigated the impact of the order of medication information on whether participants would deviate from the tool order or whether people tend to follow the tool order regardless of how the medications are ordered.

Third, from the video recording, the experimenter found that some pairs did discuss order-based strategies, such as starting from the more difficult medications. So we were interested in what "difficult" meant. Did this mean the medication had more constraints needed to be met? Or some constraints were indeed more difficult to them? In the Waicekauskas (2010) study, the definition of complex problem was based on the feasible solution space of all the four medications and co-occurrence constraints, with fewer constraints between medications considered more difficult (larger solution space). It is not defined by the difficulty of each medication. As a result, it was unclear that which one was the most difficult medication. One of goals of experiment 2 was to redefine the difficulty of each medication. The definition of difficulty can also be defined as how much time participants spent on each medication. The longer time participants spent, the more difficult it would be because this might indicate However, problem solving difficulty wasn't independently defined.

As a result, the second experiment was conducted to understand the effect of orders of medications on medication scheduling behaviors in a collaborative medication scheduling problem. Would people have a general preference to follow the tool order (perhaps to reduce cognitive effort involved in choosing another order)? Alternatively, people might be more likely to deviate from the tool order when the more difficult medications were presented first or later on the tool.

CHAPTER 4: EXPERIMENT II

4.1 Introduction

The purpose of the second experiment was to understand the effect of the order in which participants scheduled medications on medication scheduling problems. The results from the previous experiment revealed that some pairs of participants did not follow the order in which the four medications were presented on the tool when creating the medication schedule, but the results from this experiment did not clarify why they did so. Moreover, the intention of this experiment was not designed to investigate the issues of scheduling orders of medications. Experiment 2 was conducted to more directly investigate why participants may use self-initiated orders rather than following the tool order to solve medication scheduling problems, and whether this strategy influences scheduling performance.

From the previous experiment, medication scheduling order was influenced by the difficulty of medications or by the order of four medications we presented to participants on the tool. Participants would either start with the first medication on the tool or the medication that they would like to start with. In the frequency of the medication they started from, the result did show the trend some medications were more likely to be chosen as the starting point than other medications in the problems. However, it was difficult to determine why some pairs chose specific medications over other medications. As a result, the experiment two was to understand the constraints of each medication and find out the potential reasons about why participants chose the specific medication.

To understand how participants' medication scheduling behaviors were influenced by different orders of four medications in the experiment two, the order in which the four medications were presented on the E-Medtable was manipulated in each problem. If participants did take global approach to understand medication scheduling problems, it would be more likely that participants used the self-initiated orders to solve the problem when orders of medications was not facilitated the problem solving process. If participants chose the specific medication to start from and this strategy indeed assisted them to solve medication scheduling problems more easily or quickly, this result could be applied in the future interface design.

4.2 Analyzing Medication Scheduling Difficulty

The length of time for each medication in each problem could help us understand the difficulty of each medication. We assumed that the more difficult the medication was, the longer time participants needed to spend on it. As a result, by using the length of time for each medication, we could have further understanding about the difficulty of each medication.

It was also important to define difficulty independently of the scheduling time (as measured by click intervals) in order to avoid circularity. First, the types of constraints on scheduling each medication was the key to the difficulty. Each medication had different constraints. The following example illustrates constraints related to drug interactions and meal times. "Previum, for heartburn. Take 1 pill three times a day. Do not take any other medication within 1 hour. Take at least 1 hour before or 2 hours after meal." Previum had the constraints that were related to drug interactions and meal time. The drug interactions indicated the issue of co-occurrence of Previum and the other medication. The meal time indicated when the patients had meal. Based on the constraints for each medication used in experiment one, five categories were identified : (1) Drugs interaction constraints (2) food constraints, (3) time constraints, (4) time interval constraints and (5) number of doses per day. Moreover, these constraints varied in complexity Take the food constraint as the example. The food constraints included (1) no food constraints in this medication, (2) take with food, (3) do not take with food and (4) take medication before or after meals.

To better understand the scheduling difficulty of each medication, we explored the data from interface interaction in the experiment one. As we mentioned earlier, Morae (TechSmith; http://www.techsmith.com/morae.html) was used to record the time and location of participants' mouse clicks as they developed each schedule. These data could show when the participants selected each medication, how they planned the schedules or revised the schedules before completing the problem. More specifically, we could calculate the time spent scheduling each medication. Normally, the participant acting as patient would click the combo-box on the drag down menu, select the medication they wanted, click the time button to make or cancel the schedule and then repeat the same cycle for the next selected medication (figure 2). In order to calculate the amount of time spent on each medication, the timestamp of the click of combo-box for each medication was subtracted from the timestamp of the last click of changing schedules (either add or cancel the schedule) (see figure 2, blue bar). As a result, the time to schedule each medication was calculated even when participants revised the medications multiple times. The reason why we didn't include the time from the last click of changing medication schedules to the next click of combo-box (see figure 2, grey bar) was that participants would either discuss the current medication schedule plan they were working on or the next medication they were going to schedule. If we included the time from the last click of change medication schedule to the click the next combo-box, there would be variability in the data that was not directly related to scheduling processes as reflected in interface interaction. As a result, the more conservative definition was used.

Another situation was that, as we mentioned earlier, the patient clicked the combo-box for the drag down menu to select the medication, but they didn't make any changes for that medication. The time frame was also calculated and added into the medication participants selected. Although the intention of this period was ambiguous, participants would accidentally select the wrong medication or they just selected it and discussed the medication schedules without making any change. This length of time was still included in the schedule time estimate because the former only involved a short time period but the latter would tend to involve longer time. As a result, it was important to include this time frame into the length of time to make each medication.

In order to relate the idea of constraint complexity to cognitive effort involved in problem solving and develop a quantitative index of difficulty, we defined the difficulty of each constraint in terms of how many steps participants needed to develop the medication schedule (table 7). For example, if there was no food constraint for a medication, participants didn't need to think about this constraint when adding that medication to the schedule. . So a value of 0 was assigned for food constraints. If this medication needed to be taken with meals and the meal time was obvious on the medtable tool, participants only needed to identify the meal time in order to schedule (choose a time for) the medication.

This only took one step to figure out the schedule and a value of 1 was assigned for this version of the constraint. If this medication should not be taken with food, participants still needed to identify the meal time first, and then schedule the medication at feasible times other than the three meal times (breakfast, lunch and dinner). This took at least two steps for participants to figure out the schedule and 2 was assigned to this situation. If this medication should be taken 2 hours before meals, participants needed to identify the meal time first,then count 2 hours before this time, and then schedule. Because at least three steps were required to schedule the medication, it was assigned a value of 3. In other words, the larger the assigned number was, the more difficult that criterion (constraint) was, resulting in an ordinal variable.

In this dataset, two levels of approaches could be used to understand the difficulties of the problem: task-level and medication-level. Because the former the difficulty level of the whole task (including the 4 medications) is hard to define .medication difficulty was based on each constraint for each medication. For example, one medication had its own difficulty on food, time and time interval constraints. But another medication also had its own difficulty on time interval and drug interaction. The difficulty of the whole task couldn't be the average of every constraint because they were ordinal scale. The later was a better approach and results revealed the effect of different levels of complexities on the total trial time. But taking this approach caused analytic problems because some of the data were not independent. In these data, each medication was taken as a data point and each pair had four tasks. 96 (24 pairs x 4 tasks) data points were used and every four medications might come from the same task and every four tasks were done by the same pair.

Generalized estimating equations (GEEs) were used to handle the clustering/dependency in the data. GEEs were extended from generalized linear models (GLMs) for a regression setting with correlated observations within subjects (Liang & Zeger, 1986). In the GEE, the first step was to define a correlation matrix. Following Diggle, Liang, and Zeger (1994), the exchangeable work correlation matrix was applied to our data. Then the second step was to decide the distribution and link function. After running different distributions, the Poisson distribution was chosen and link was identity.

The software SAS 9.1 PROC GENMOD was used to run this model. The results of the best fit model from the first experiment showed that the drug interaction constraints, time interval constraints, time constraints and number of doses had significant effects on solution time ($X2 = 295.1$, $p < .001$; $X2 = 65.252$, $p < .001$; $X2 = 453.855$, $p < .001$; $X2 = 571.149$, $p < .0001$). The results implied that medications with drug interaction constraints, time interval constraints, time constraints and increasing number of doses took longer to schedule, suggesting problems with these medications were more difficult to solve. Results from this analysis were used to develop medication scheduling problems in the second experiments.

Figures and Tables

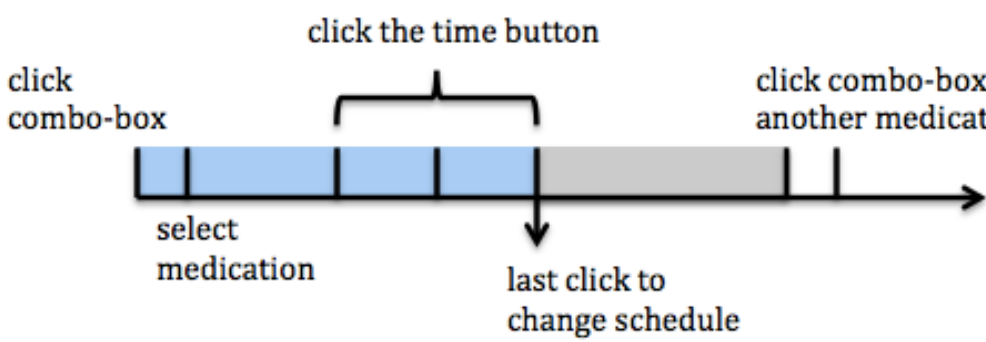

Figure 2. The timeline of making medication schedule. The blue bar indicated the length to make the medication plan.

Table 7. Definition of medication schedule difficulty in terms of constraints that varied in terms of required processes.

Drug Interactions Constraints	
0	No drug interactions
1	Have interactions with one medication
2	Have interactions with two medication
Food constraints	
0	No constraints with food
1	Take with food
2	Do not take with food
3	Take before or after the meal
Time Constraints	
0	No time constraints
1	Take in the morning/bedtime, take one hour before bedtime
2	Do not lie down for at least 4 hours afterwards and take at least four hours before bedtime
Time Interval Constraints	
0	No times interval constraints
1	Specify 10-12 hours apart or 4 hours apart.

4.3 Medication Scheduling Problems

In the second experiment, the problems (see appendix B) were created based on the difficulty of problems. Different medications had different constraints and each constraint had different levels of difficulty that may reflect on how much cognitive effort participants invested, as suggested by the GEEs model analysis of solution time in Section 4.2. For example, the results from that analysis showed that the drug interaction constraints had a greater influence on solution time than other constraints.

4.4 Procedure

The procedure and instructions for Experiment 2 were similar to Experiment 1, except for some changes of the medication scheduling tests. As before, older adults participated in pairs in this experiment. After obtaining their consent, they filled out the demographic survey and the Advanced Vocabulary test (Ekstrom, et al., 1976). Then they were led to the experiment room. At this time, they were notified of their roles as provider or patient for the collaborative medication scheduling task, and were instructed in how to use the e-Medtable. As in Experiment 1, the patient was given the patient routine information including daily event time and work schedules. The patient routine information was the same as in Experiment 1. As before, the provider was given medication information. However, the medication problems were different in Experiment 2 (see appendix B). Before the task started, participants were given one minute to read and become familiarity with the material (daily routine for patient; medication information for provider). Then they were asked to work together to develop the patient's medication schedule plan based on the provided information, and had 12 minutes to complete the task. Total solution time was measured by stopwatch. As before, the patient was in charge of documenting the schedule on the tool.

All participants were first given two sample problems in the same order (one simple and one complex) in order to familiarize them with the collaborative medication scheduling task and the e-medtable tool. The sample problems were the same ones used in the first experiment. Before each problem, participants were told that schedules with fewer medication times were better, because they were easier to remember and follow (Osterberg & Blaschke, 2005). Then six problems were given to participants and the order of the problems was counterbalanced across participants using a Latin square design. Similarly, whenever participants indicated they completed the task, the experimenter would stop the stopwatch. The experimenter would ask the patient to read back their medication schedule plan. The purpose of the read-back was to check the patient's understanding about his medication schedule plan and if participants found out any mistake, they could revise the schedule again. And the time to revise the schedule would be added to the total solution time. After the read-back, both the patient and provider were given the NASA-TLX to fill out the workload of this problem.

Participants took a 5-minute break after they completed the two practice problems and two of the six problems. . After the break, they completed the rest of the problems. After all the tasks were finished, participants completed the Letter and Pattern Comparisons (Salthouse, 1991b). Then Short Text of Functional Health Literacy (STOHFLA; Baker, Williams, Parker, Gazmararian, & Nurss, 1999) was given to the patient; meanwhile, the provider was asked to do the Letter-number Sequencing Tests to measure their working memory span. After both finished the tasks, they would take turns to do the other task. The total time for this experiment was 2 to 2.5 hours. Each participant was given $25 for participation.

4.5 Study Design, Dependent Variables and Ability Measures

Based on the results GEE analysis, 6 problems were constructed based on the difficulty of each medication (see table 7). There were three types of problems: 1) of problems with drug interaction constraints, 2) problems without interactions and 3) control problems. Control problems included medications that have same difficulty (level: 1-2) without drug interactions. For each type, there were two problems, one in which the four medications were presented from simple (level: 0 or 1) to difficult (level: 2 to 3), and one in which the medications were presented from difficult (level: 2 to 3) to simple (level: 0 or 1). The orders of four medications were also counterbalanced. This was a 3 (types of problem: drug interaction, no drug interaction and control) X 2 (orders of medication: complex to simple and simple to complex) within subjects design. Each pair of participants completed six medication scheduling problems.

The dependent variables and ability measures were similar to the first experiment except for some differences in questionnaires, as described below. As in Exp 1, dependent variables were categorized into three types: (1) problem solving performance, (2) workload and (3) interface interaction. Problem solving performance included the measures of solution completion time and solution accuracy. Workload was measured for each problem by NASA-TLX (Hart, 1988). The interface interaction was again recorded by Morae and the way to code the click and count the frequency remained the same as in Experiment 1.

The ability measures included the demographic survey, Advanced Vocabulary Test, Letter and Pattern Comparisons Tests, Letter-number Sequencing Test and STOFHLA. The Partner Awareness, tool preference questionnaire and tool usability surveys were not administrated in this experiment.

4.6 Participants

26 older adults (13 pairs) participated in this study and were recruited from the local community (Table 8). One pair was excluded because their solution time on one problem was over 30 minutes. All the participants were 60 years and older (age: M = 70.14, SD = 5.62). Twenty participants were female (83%). All participants were paired and randomly assigned to the role of patient and provider. All the pairs were received 6 problems. Participants were screened to meet several criteria used in the previous experiment.

Tables and Figures

Table 8. Means of demographic survey and of Letter and Pattern Comparison Task (speed of processing).

Variable	Pairs (N = 12)	SD
Age (years)	70.14	5.62
Education (%)		
Graduate High School	25.00%	
Some College	25.00%	
Graduated College	16.67%	
Advanced Degree	33.33%	
Self-rated Health Scores	5.375	1.17
Vocabulary Score	10.875	3.66
Speed of Processing	11.125	3.93
Working Memory Score	8.875	2.46
STOFHLA	35.375	0.82

4.7 Results

The problem solving variables of accuracy and total trial time were analyzed by a 3 (types of problem: drug interaction, no drug interaction and control) X 2 (orders of medication: complex to simple and simple to complex) ANOVA with repeated measures. An alpha .05 level was used in all the statistics. If the main effect was significant, pairwise comparisons with Bonferroni correction were used to test the differences.

Problem Solving Performance

Problem Solving Accuracy. The results from figure 3 show that accuracy was very high across all three types of problems. The two-way ANOVA test didn't show any significant main effect or interaction effect on accuracy. Only the main effect of type of problems approached significance ($F(2,10) = 3.18$, $p = .09$), reflecting numerically lower accuracy score for problems with drug interactions

Total Solution Time. The results for total solution time showed there was significant main effect of problem type on the total trial time ($F(2, 10) = 6.017$, $p = .019$).

The planned comparison tests showed that total solution time was longer for drug interaction problems (M = 453.79) than for no drug interaction problems (M = 307.54), p = .014, and for control problems (M = 323.875), p = .064.

Subjective Workload: NASA-TLX

NASA-TLX was a survey with six questions, measuring the subjective opinions about the problems. As a result, six scores were received whenever participants completed one problem. The principal components analysis (PCA) was used to reduce the complexity of the data and also identify the pattern in the data. For each problem, more than half of the variance could be explained by two factors (75 % - 85%). The factor loadings from the PCA results were used to create the TLX composites for each problem. Then the TLX composites scores were analyzed by Types of Problems X Orders of Medication X Role ANOVA repeated measures.

The results showed that there was a significant main effect for orders of medications (F = 7.204, p = .023, df = 1; Table 9.) and the effect for type of problems approached significance (F = 3.22, p = 0.93, df = 2; Table 10). The planned comparisons showed that the subjective workload was higher when orders of medications was from complex to simple (M = 107.28) than from simple to complex (M = 78.95).

Interface Interactions

Similarly, the interface interactions about number of revisions and tool order (following the tool order and start self-initiated order) were analyzed by a 3 (types of problem: drug interaction, no drug interaction and control) X 2 (orders of medication: complex to simple and simple to complex) ANOVA with repeated measures. An alpha .05 level was used in all the statistics. If the main effect was significant, the pairwise comparisons would be continued to test the differences. Comparison tests were made by Bonferroni tests.

Following Tool Order vs. Self-initiated Order. Based on the data of interface interactions from Morae, orders of medications that each pair took to solve each problem was coded. If participants followed the tool order we presented to them, 1 was recorded for the problem; if participants took any other (self-initiated) order to solve the problem, 0 was recorded. About 30% of users took self-initiated orders when solving the medication problems. The ANOVA results showed that the type of problems approached significance (p = 0.056; df = 2). There were no significant differences for pairwise comparisons. In order words, the increased workload associated with complex simple order of constraints is not related to the following tool order or not.

Number of Revisions. The number of revisions variables was based on the order in which participants scheduled the medications, and reflected the number of times a medication was revisited and the medication schedule was changed. Neither the main effect for type of problems($F(2, 9) = 1.607$, $p = 0.248$), order of medications ($F(1, 11) = 0.007$; $p = 0.933$), or their interaction ($F(2, 9) = 0.134$; $p = 0.876$) was significant.

Tables and Figures

Figure 3. Mean percentage accuracy. SD = standard deviation.

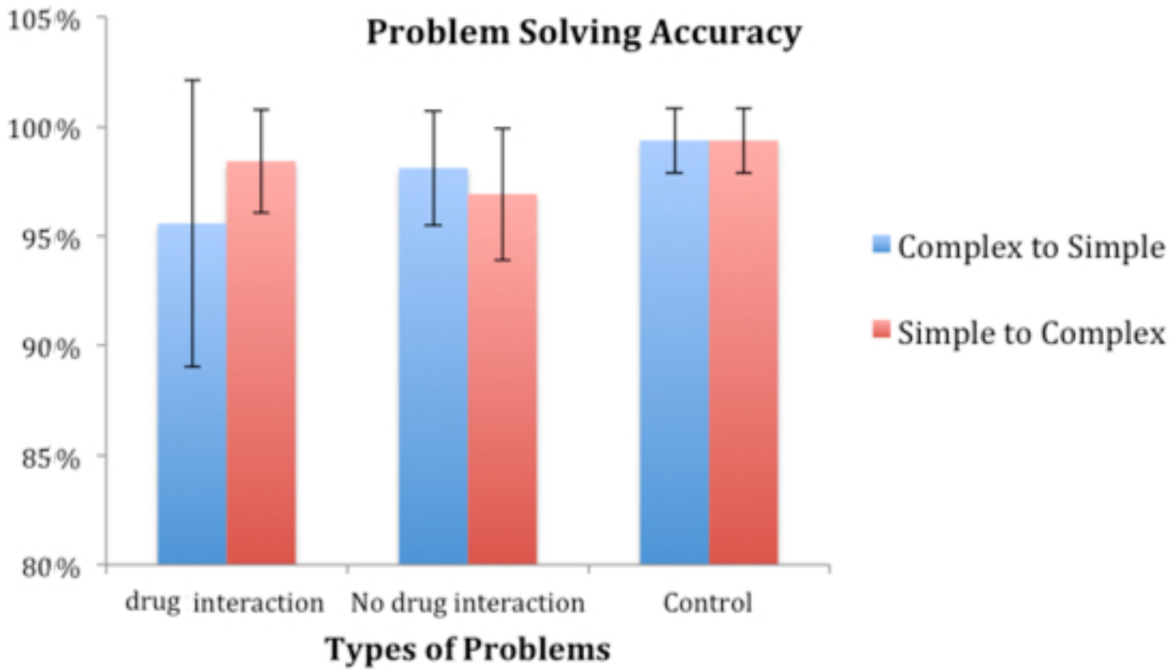

Table 9. The means and standard deviation of workload by orders of medication.

Orders of Medication	**Mean**	**SD**
Complex to Simple	107.284	19.739
Simple to Complex	78.95	11.894

Table 10. The means and standard deviation of workload by types of problems.

Types of Problems	Mean	SD
Drug Interaction Problems	115.753	21.421
No Drug Interaction Problems	87.177	16.766
Control Problems	76.422	15.151

Table 11. Percentage of pairs who followed the tool order when solving the problem.

Types of problems	Order of Medications		
	Complex to Simple	**Simple to Complex**	**Average**
Drug Interaction	58.33%	66.67%	62.50%
No Drug Interaction	75%	91.67%	83.33%
Control	58.33%	58.33%	58.33%
Average	68.39%	72.22%	

4.8 Discussion

The purpose of the experiment 2 was to understand whether people have preferences to follow the tool order or self-initiated order when solving medication scheduling problems. The medication problems were created based on the difficulty of the medications in the problem and presented in different orders (e.g. simple to complex and complex to simple). Participants needed to complete different types of problems in different orders of medications.

Problem Solving Performance

The results from this experiment showed only types of problems were significant on problem solving performances including problem solving accuracy and total solution time. Orders of medications on the tools didn't have effect how their problem solving performances. The drug interaction problems took longer time and were harder to solve (higher workload and lower accuracy). This result was the same as Waicekauskas (2010) result: it took participants longer time and they had less accuracy when solving harder problems.

Although the order of medications on the tool didn't effect show problem solving performances, it did effect on participants' subjective workload associated with problem solving. Participants worked harder to solve problems in which medications were presented from complex to simple than from simple to complex. Participants needed to spend more cognitive workload when solving drug interaction medications.

Interface Interactions

Like previous experiment, about 1/3 of pairs chose self-initiated order to solve medications problems. Overall, participants still tended to follow the order of information on the interface. The results showed that only types of problems had significant effect on their problem solving strategies (following tool order vs. self-initiated order) and orders of medications didn't have any effect on their problem solving strategies. People tended to follow the tool order in drug interactions and no drug problems but deviate more in control problems. For control problems, it won't matter whether users follow the tool order or not because the orders of scheduling medications have less influence on how to solve the problems. For drugs interactions and no drug interactions problems, participants tended to follow the orders on the interface more. It was possible that they just assumed the order of medications on the interface was perfect. They don't need to worry that or they just focused more on how to figure out the medication schedules without thinking how to solve medication scheduling problems more easily.

Limitations

There are several limitations in this study. The first limitation is that, in order to keep consistency between the two experiments, most instructions and the interface were the same as the first experiment. Participants were instructed to figure out what the most optimal schedules for each problem were. They were not instructed to solve the problems as soon as possible which might encourage them to figure out how to solve the problems more efficiently. They would consider which medications should be scheduled first.

Secondly, there was a limitation on how medication scheduling problems were presented on the interface at default. When the program was open for each problem, the first medication on the interface was already selected in the combo-box at default. Since it was already selected, this might imply participants to start with the first medication without choosing different medications. As a result, participants tended to follow the tool order presented by the interface without really thinking through which medication should be scheduled first. Participants needed to consciously choose different medications. In the second experiment, some of participants did say "Let's start with the fourth medication because it was the most difficult one."

The third limitation of this study was the small sample size: only 12 pairs. This might result in limitation data analysis. It was hard to identify the signification effect of orders of medications and other interactions, resulting in inconclusive results. Also, the results might not be generalized to larger population based on this study alone.

CHAPTER 5: CONCLUSIONS

Medication adherence is a very important issue in United States. It is especially challenging for older adults because they are often prescribed multiple medications for chronic illness, yet have more limited cognitive resources to manage these medications. Successful medication adherence involves many behaviors and responsibilities among healthcare organization providers and patients. It often requires effective communication and collaboration with healthcare professionals. A previous study (Waicekauskas, 2010) provided evidence that a tool designed to support collaborative planning for taking medication (e-MedTable) was more effectively used than a less structured paper-based tool to support medication scheduling in a simulated collaborativeproblem solving adherence task. However, the results of this study provided limited insight into how the e-MedTable supported problem solving. For example… process still remained unknown.

This study tried to understand how patients and providers collaboratively solve medication scheduling problems in a simulated patient-provider interaction and the impact of different orders of information display on problem solving strategies. The interface interaction analysis from the first experiment did shed some light on how our participants solved the medication scheduling problems collaboratively, and suggested directions about how to design the second experiment. In the second experiment, the results showed that order of medication didn't have any impact on how participants solve the problems but it did influence how people perceived the difficulty of problems. If the medications were presented from most complex to simple, participants showed higher subjective workload when they solved the problems. They would think this medication scheduling problem is harder, it took them more effort to solve the problems. Thus, this result implied that, to make participants feel easier to solve medication scheduling problems, the order of medications on the interface should presented from simple to complex.

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APPENDIX A: MEDICATION SCHEDULING PROBLEMS FOR EXPERIMENT 1

The medication scheduling problems used in the experiment 1 that has been used in this thesis may be found in a supplement file named medication_problem_experiment1.jpg

APPENDIX B: MEDICATION SCHEDULING PROBLEMS FOR EXPERIMENT 2

The medication scheduling problems used in the experiment 2 that has been used in this thesis may be found in a supplement file named medication_problem_experiment2.jpg