THE E-MEDTABLE: DEVELOPMENT AND TESTING OF AN ELECTRONIC COLLABORATIVE TOOL TO SUPPORT MEDICATION SCHEDULING

BY

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THESIS

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ABSTRACT

Successful self-health management often includes a medication regimen. Medication adherence – taking medication according to how it is prescribed – is essential to effective treatment. It is even more crucial for older adults, who typically take multiple medications. Successful adherence depends on adequate knowledge about the medication, which often depends on effective communication with providers. Unfortunately, physician and patient communication is often inadequate. Successful adherence is also related to integrating medication taking with a daily routine. Previous research tested a paper tool (MedTable) to support provider-patient collaborative planning. The tool improved problem solving performance in a simulated medication scheduling task. The tool acts as an external workspace that reduces the cognitive demands of learning about and planning how to take medication, while also facilitating collaboration.

Motivated by the increase in availability and benefits of health care information technology, an electronic interface, the e-MedTable was developed from the MedTable. In this study, the e-MedTable and a modified MedTable were compared to a less structured paper tool (Medcard) similar to those used in actual health settings, in order to see the effect of external aids on problem solving and collaboration. 144 community dwelling adults over 60 years old participated in pairs in a simulated patient-provider medication scheduling task. Each pair solved four medication scheduling problems (2 simple and 2 complex) using one of the three tools (MedTable, e-MedTable, Medcard). Measures were problem solving performance (solution accuracy and time), perceived workload, quality of collaboration, and usability. Participants created more accurate medication schedules when using the MedTable rather than the Medcard. The two structured tools reduced perceived workload and had higher usability than the less structured Medcard. Some aspects of collaboration were higher for users of the e-MedTable compared to the Medcard. Finally, there was no evidence that older adults had difficulty using the computer-based tool, which suggests that a computer-based tool could be an effective intervention for improving provider-patient collaboration in actual health care settings.
To my God and Treasure
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CHAPTER 1: INTRODUCTION

The potency of medication is ever improving; medication can now be an effective treatment to many illnesses that were once only treatable with more invasive techniques. Although the increase in the efficacy of medication is a good thing, it means that there is more pressure on the patient to properly take their medication. The taking of medication as a health professional prescribes is called adherence (Osterberg & Blaschke, 2005). Unfortunately, adherence is not a simple task. To begin with, a person has to assess whether taking medication is worth it. Do the benefits outweigh the costs? Then, the person must develop an adherence plan, often without external support. Finally, the person must implement the developed plan into daily life. Any and all of these steps can break down, especially if the medical provider remains uninvolved.

However, the Institute of Medicine rightly thinks that the provider should get involved (Apsden, Wolcott, Bootman, & Croenwett, 2007). A provider can help to support any of the steps, whether it is highlighting the benefits of adherence or collaborating with the individual to develop an adherence plan that would be easy to implement. For this to happen, communication between patient and provider must become informative, collaborative, and effective. Alas, it could use a little help right now.

This study looks at the possibility of transforming patient-provider communication through the use of an external collaborative artifact. An external collaborative artifact is a computer- or paper-based tool that externalizes information to be shared between participants. Cognitive resources, such as working memory, are supported by having this information immediately available; no search through memory is necessary. The tool also becomes a means for performing the task. Scheduling 5 medications in one’s head can be difficult without writing them down, but, if one was given a daily schedule with the medication information already written on it, the task is different and probably easier. Furthermore, it is easier for the task to become collaborative when the information and actions upon that information are externalized.

Therefore, a computer-based tool (the e-MedTable) was developed to become the external workspace for a collaborative medication scheduling task. The e-MedTable was
modeled after a paper-based tool that proved successful in a simulated patient-provider study (Morrow et al., 2008). This thesis discusses the development and testing of the e-MedTable. The goal is that the tool would prove to be an effective collaborative device that would eventually lead to an interface to be implemented in clinical settings to support patient-provider communication concerning medication adherence planning.

Organization of Thesis

Chapter 2 is a literature review of the problem of medication adherence, its factors, and possible solutions for improving adherence, the primary being a structured tool for collaborative medication scheduling. Chapter 3 presents the methodology of the experiment that tested the benefits of external collaborative support tools in a medication scheduling task. Chapter 4 describes the findings from the present study. Chapter 5 discusses the findings, the implications, and the limitations of the present research. Chapter 6 concludes the thesis and suggests future directions.
CHAPTER 2: LITERATURE REVIEW

Background

In 1999, the epidemic of medical errors in the United States healthcare system was brought to the forefront of the public view. In that year, the Institute of Medicine (IOM) published a report that claimed that at least 44,000 (and possibly as many as 98,000) people die annually in hospitals due to preventable medical errors (Kohn, Corrigan, & Donaldson, 1999). Furthermore, errors also cause hospitals to suffer a monetary cost of anywhere between $17 and $29 billion annually. The problem, the report stated, is not that there are “bad apples” running amok in the healthcare system, but rather the state of the system itself. The report advocated numerous improvements, starting with bringing this problem to the focus of the nation so that leadership, research, and best practices from other industries may influence this field. This report has done exactly that, plus it has caused many other aspects of the healthcare system to be put under watch, including the processes of medication prescribing, dispensing, and administering.

One of the IOM’s later reports focused solely on preventable adverse drug events (ADEs), which are injuries due to medication that arise from medical errors (Apsden et al., 2007). The committee behind this 2007 report estimated that at least 1.5 million preventable ADEs occur annually whether in a hospital, clinic, or outpatient setting. This marks a drastic shift in attention from solely on the healthcare system within a hospital or clinic to the view that the healthcare system has an overarching influence on safety in ambulatory care. The primary call of this paper was to improve collaboration between patient and provider (doctor, nurse, or pharmacist), use information technology to reduce medical errors, and improve medication labeling and packaging to reduce the number of preventable ADEs, which is ultimately a call to improve patient adherence of medications both at home and within clinical settings.

Medication nonadherence, which is the failure to follow the medication regimen prescribed by health professionals (Osterberg & Blaschke, 2005), is a serious issue in America, even if it is only based upon the sheer numbers: about half of all Americans take at least one prescription medication (Mitchell, Kaufman, & Rosenberg, 2007). Thus, even if medication adherence errors were rare, merely the fact that medications are so widely used would entail
that millions of people could possibly be at risk. Unfortunately, the numbers are not small. In fact, nearly half of the 3.5 billion annual prescriptions filled in the United States are not taken as prescribed (Osterberg & Blaschke, 2005). Failure to take medications as prescribed can lead to significant morbidity, mortality and additional healthcare costs. Additionally, non-adherence costs the healthcare system about $100 billion annually (McDonnell & Jacobs, 2002).

Issues with adherence increase with older adults as this population often takes many more medications; adults over 65 take on average 5 or more medications. Indeed, more than 90% of adults over 65 take at least one medication, and about 20% take more than 10 medications (Mitchell et al., 2007). Therefore, even if the rate of nonadherence does not increase with age, the opportunity for error is greatly increased for older adults solely due to the amount of medications. Unfortunately, older adults also experience age related declines in working memory and recall abilities, processing speed, cognitive inhibition, and perceptual-motor function (Park, 2000). These declines can exacerbate the already complex problem of medication adherence.

**Factors of Adherence**

On the surface, appropriate medication adherence results from the successful development and implementation of a medication regimen (Morrow & Wilson, 2010). And yet there is so much that goes into those two factors. These two factors are influenced by three main elements: a) the medication and illness, b) the individual differences of the patient, and c) the healthcare system (Park & Jones, 1997).

**Medication and illness.** First off, medication and illness influence adherence in multiple ways. Since illness influences what medications are prescribed, medication regimens vary by diagnosis (and the habits and behavior of providers). Medication regimen’s can differ in complexity, some regimens will be easier to understand or follow, and thus adherence depends on complexity. Furthermore, medications vary in the side effects that a patient may experience. Any ill-wanted side effects are likely to increase the likelihood of nonadherence. This also ties in with the patient’s understanding and mental representation of their illness. Is the illness particularly severe in which nonadherence would result in severe consequences? The patient’s
perception of the medication’s impact further supports adherent or nonadherent behaviors (Park & Jones, 1997).

**Patient-level factors.** Next, adherence is influenced by the individual and patient-level factors which include age, cognitive abilities, education and literacy, and socio-economic status (SES) (Morrow & Wilson, 2010). As mentioned earlier, older adults have more opportunity for error based on the amount of medication they take, and the understanding and implementing of an adherence plan requires heavy reliance on working memory and processing speed, which decline with age, regardless of education and verbal ability (McDaniel, Ryan, & Cunningham, 1989; Park, 2000). Furthermore, older adults have more issues with comprehension, memory and adherence of physician instructions than younger adults because of age related declines in the cognitive resources required for these tasks (Brown & Park, 2002). Age, education, literacy, and SES are all connected to health literacy, the ability to understand and interpret health information. Inadequate health literacy affects numerous health aspects such as use of preventative medicine, adherence to medical instructions (such as found on medications), understanding of one’s personal health, and at home self-care (Wolf, Gazmararian, & Baker, 2005).

Although there are numerous patient level factors that (negatively) affect the adherent behaviors of older adults, this is not the end of the story. Prospective memory training can have a positive impact on adherence often through the use of implementation intentions, which is using prospective memory to plan when medications will be taken prior to starting a medication schedule (Black & Scogin, 1998; Chasteen, Park, & Schwarz, 2001). This is good news for older adults as research on prospective memory has shown that context can negate the effects of cognitive decline (Wilson & Park, 2007). Furthermore, prospective memory can be supported by the use of memory aids (Einstein & McDaniel, 1990). Tools that both allow the offload of cognitive demands required for successful adherence as well as support prospective memory can reduce many of the causes of non-adherence in older adults, including omission errors (Park, Morrell, Frieske, & Kincaid, 1992). However, successful training with tools or interventions would most likely require efficient and adequate communication between patient and provider to be viable.
**Healthcare system-level factors.** The healthcare system factors include financial costs, pharmaceutical practice (medication packaging and labeling), and patient-provider communication (Morrow & Wilson, 2010). Financial burdens influence whether or not the patient is receiving the necessary medications; it is impossible to adhere to medication that one does not have. The labeling on medications, which is often the patient’s closest source for medication instructions, influences the patient’s understanding and resulting adherence plan. Understanding medication warning labels is a necessary step in adherence, and yet some labels are too hard to understand or are misinterpreted, especially by patients with low health literacy (Davis et al., 2006). In fact, there has been a lot of focus upon improving medication labeling, some of which argues for more explicit language to assist in creation of an adherence plan (Wolf et al., 2007). Finally, the quality of patient-provider communication impacts adherence, as poor collaboration leads to poor at home self-care (Apsden et al., 2007). Quality of provider-patient communication can also influence the cognitive demand medication adherence has on the patient.

Ideally, the communication between patients and providers would involve not only educating the patient, but also assessing the patient’s knowledge and collaborating on the development and implementation of a medication plan. Unfortunately, that is not the case; there are several issues that arise in patient/provider communication. Principally, providers often overestimate a patient’s health literacy, and according to one study fail to assess patient understanding 98% of the time (Bass III, Wilson, Griffith, & Barnett, 2002). This is regrettable in that patient ability to recall and comprehend health information is often predictive of adherence, and yet recall and comprehension are barely assessed even in those with low health literacy (Schillinger et al., 2003). Also, failure of the patient and provider to agree on a plan for taking medication, whether by choice or misunderstanding, leads to negative health outcomes (Machtlinger et al., 2007). Not only is patient/provider communication missing steps in assessing understanding, the communication may include additional gaps in information. In fact, doctors often omit 40% of the information that should be communicated when prescribing new medication; this information includes duration of intake, frequency/timing, number of pills, and adverse events (Tarn et al., 2006).
Patient/provider communication is often inadequate for multiple reasons. Providers have a limited amount of time with the patient (Apsden et al., 2007). Providers also have inadequate communication training. This results in the quality of communication being affected by the socioeconomic class of the patient (Willems, De Maesschalck, Deveugele, Derese, & De Maeseneer, 2005). Patients of lower socioeconomic class receive less positive utterances from their doctor and have less control of the communication, whereas the doctors communicating with these patients fail to present information in an interactive, consultation style and perceive the patient as being not interested in health topics (Willems et al., 2005). Thus, the patient fails to be engaged with the doctor and both participants are reinforced into this spiral of bad communication. Finally, patients and providers often communicate in different ways. Patients tend to tell a narrative about their ailment, and providers often interrupt the narrative to get answers to a list of inquiries (Haidet & Paterniti, 2003). This often leads to communicative dissonance rather than harmony. Providers need to be willing to adapt and improvise their communication styles to the styles of their patients (Haidet, 2007).

Distributed Cognition, Collaboration, & External Artifacts

Clearly, one of the main issues behind preventable ADEs is the variable, and often poor, quality of communication between patients and medical providers. Indeed, for the past couple of decades, there has been a patient-centered health care movement calling attention to the problem of patient-provider communication (Stewart et al., 1995), but the focus has been more on fleshing out the problems and less on the techniques and strategies that will transform the existing standards. Without a doubt the problem has not gone away, the 2007 IOM report (Apsden et al., 2007) contended for improved quality of patient and provider communication. So how can the current condition of clinical communication shift paradigms to allow for more active engagement of both parties? It may be helpful to view this dialogue through the lens of
macrocognition, or distributed cognition. This theory supports the idea that cognition extends beyond a single individual to include all individuals within a collaborative group and any aspect of the environment such as technology that stores information or supports cognition (Hutchins, 1995; Klein et al., 2003). In essence, no one individual stores all of the necessary information required to perform a task or solve a problem.

By identifying processes involved in collaboration, the distributed cognition approach helps explain how and why patient and provider communication often fails, particularly related to medication scheduling. For example, the provider may be an expert in medication and health practices, but he is not an expert on the patient’s daily experience and routine. Only the patient can serve in that role. Furthermore, this theory also allows for the use of external artifacts that can assist in the task.

**External artifacts support problem solving.** External artifacts can serve multiple functions in distributed cognition. For one, they can be useful as external representations to assist in problem solving. External problem representations, such as diagrams, are useful in lowering cognitive demands since they support perceptual inferences and index information for easy retrieval (Larkin & Simon, 1987). External representations also transform the task since they move some task relevant information out of memory onto a physical medium where memory search is unnecessary and high-level, abstract interpretation is minimal (Zhang & Norman, 1994). Furthermore, external artifacts serve as more than memory aids; they can both shift cognitive effort to more opportune times and act as a resource for organizing performance (Hutchins, 1995). By moving aspects of the problem to an external medium, cognitively intense operations are reduced, and the complexity of the problem may be decreased. Moreover, some representations may be more useful for specific tasks than other representations. More effective representations require encoding that is more compatible with the mental encoding necessary for the task (Zhang & Norman, 1994). For example, medication information presented in a matrix proved to be more helpful than a list when participants needed to answer inferential questions about a medication regimen (Day, 1988). Therefore, a matrix of medications would be more useful than a medication list for supporting the cognitive processes that relate to medication planning (Seals & Duffy, 2005).
**External artifacts and collaboration.** Secondly, external artifacts can be used to support collaborative processes, such as conversational grounding between individuals. Conversational grounding is the process in collaborative communication in which the participants coordinate what is comprehended – their common ground, which includes mutual knowledge and assumptions (Clark & Brennan, 1991). Common ground can be divided into two categories, content versus process (Convertino et al., 2008). Content common ground involves the core shared knowledge of the task or problem, such as medication information or details of the patient’s routine. Process common ground involves the mental models of the participants, or how they structure the task or problem in their mind. This relates to the patient’s mental representation of their illness; the importance of adhering to a medication plan depends upon the severity with which they view their illness. In either form, common ground has to be continually updated, which involves a three step process: one of the participants initiates the conversation (or a new subtask), then information is presented to the other party, and finally the addressee accepts the information as mutually understood (Clark & Brennan, 1991).

Unfortunately, any of these steps can break down and misunderstandings can occur. The addressee may not fully understand the presented information, or after correctly understanding the information, fail to adequately update his/her own mental model of the situation (Morrow, Rodvold, & Lee, 1994). For example, the patient may not fully understand what a medication direction means, (“empty-stomach?”) or even if understanding the direction, fail to update their mental model (“if my stomach is not empty until a couple hours after I eat, that means I can’t take this medication right when I finish dinner.”). On the other hand, the addressee may fail to give the speaker adequate feedback that the information was understood or not (Morrow et al., 1994). Often times these misunderstandings can be corrected by a simple question from either the speaker or the addressee. In clinical communication, where patients often failing to speak up with clarifying questions, the provider would do well to request feedback to ensure grounding (Schillinger et al., 2003). Other times, deeper misunderstandings involving process common ground require more time to clarify (Morrow et al., 1994). And yet the results are something all parties should be invested in, as
successful grounding results in the conversation becoming more efficient, which leads to shorter turns and increased turn taking (Convertino et al., 2008).

**External artifacts support collaboration.** So how do external artifacts assist in this grounding process? Well, collaborative communication is multimodal (Convertino et al., 2008); visual cues involving deictic gestures and an external artifact can assist in grounding (Kraut, Fussell, & Siegel, 2003). Indeed, shared visual space, such as an external artifact would occupy, improves conversational grounding (Gergle, Kraut, & Fussell, 2004a; Gergle, Kraut, & Fussell, 2004b; Kraut et al., 2003). Actions upon visual information facilitate comprehension and the verification of mutual knowledge between collaborative partners (Gergle, Kraut, & Fussell, 2004a). For example, when one individual performs the action requested by the other individual, confirmative language is unnecessary; the action itself either verifies understanding or not. Thus, actions within a shared visual space not only make language more efficient, but they also minimize language expression - via deictic references - or eliminate the need for some language altogether as in the previous example. Consequently, the visual information helps to improve the efficiency of communication by lowering the ambiguity of some expressions (Gergle, Kraut, & Fussell, 2004b). The often ambiguous "OK" now gets clarity from the subsequent actions of the speaker. Therefore, common ground is fostered through efficient expressions in the presentation stage and easier comprehension monitoring in the acceptance stage. Furthermore, the initiation stage is improved because the shared visual space allows task coordination. The visual space helps to answer the questions: "What's done?" and "What do we still need to do?".

External artifacts may also help structure collaborative medication planning. As mentioned above, medication planning is a collaborative task in which information is distributed across the participants. For this task, external artifacts can serve as a support for cognition and memory. Instead of the patient relying on remembering the provider’s instructions, the information could be offloaded to a shared external artifact. The provider could then give further instructions and be more complete since the patient’s cognitive abilities would not be taxed. Likewise, the provider would not have to commit the particulars of the patient’s schedule to memory, and still be particular with the scheduling for the patient’s
benefit (“I see that you have breakfast at 8am, well you can take this medication at that time”). The result is that the patient and provider develop shared understanding about the medication plan. Thus, as conversational grounding develops, the external artifact becomes the means to performing the scheduling task itself. The scheduling is not only discussed, but it is also documented. Interacting with the external artifact engages both parties, questions are exchanged, and nonverbal cues become evidence of comprehension or misunderstanding. The result is that the provider and patient develop a medication schedule that the patient is invested in and more likely to adhere to. The provider can also use implementation intentions while scheduling to improve adherence. Thus, external artifacts can transform clinical communication and promote collaboration in medication scheduling from addressing the patient’s mental representation of their illness through grounding to developing an implementable plan through collaboration.

This could be the first step to changing the perspectives of the patient and provider. The hope is that patients would see that they are more than merely cogs in the system; rather, they are important participants in their health care and actively responsible for their own self-care. Furthermore, if the doctor can shed the teacher-pupil paradigm and see that the patient has something to offer, perhaps true collaboration between patient and provider will develop. Ideally, collaboration would spread beyond the boundaries of medication planning into all aspects of health and wellness, ultimately improving patient safety in the long run. Moreover, if the tool is easy to use, providers may be motivated to use it despite limited time with patients.

**Interventions and External Artifacts in Healthcare**

So where does one begin? Should the patient be educated, or the doctor? Well, several agencies have stressed to patients that they need to get involved with their healthcare and interact with their providers. Since 2008, the Agency for Healthcare Research and Quality (AHRQ) has been running a public service advertisement entitled: "Questions are the answer" - calling for patients to engage in asking questions of their provider during consultations (www.ahrq.gov/questionsaretheanswer/). They emphasize that asking the right questions will
help a patient understand his health and improve his decision making when selecting a treatment option. Or in the case of medication taking, a more informed patient is a more adherent patient. AHRQ is not alone in advocating patients to ask questions of their doctor. The National Patient Safety Foundation (NPSF) has narrowed down their focus to just 3 main questions. The program "Ask Me 3" urges patients to ask their doctors (www.npsf.org/askme3/):

1. What is my main problem?
2. What do I need to do?
3. Why is it important for me to do this?

Once again, the thought is that more informed patients are safer and more likely to give feedback to their doctors. The NPSF program is also targeted at providers to get them to encourage their patients to ask questions. Unfortunately, a recent study has shown that the NPSF intervention has not proved to increase question asking nor adherence (Galliher et al., 2010). The study reports that the intervention also fails to target those with low health literacy, which are those who would most benefit from improved patient-provider communication.

Provider-specific interventions. Thus for an intervention to be successful, it has to do more than urge patients to ask questions. Rather, an intervention ought to transform the patient-provider interaction itself. External artifacts can be the route in which collaboration develops in this interaction. Fortunately, external aids are not new to the realm of healthcare. Oftentimes external artifacts are used for provider-provider communication. Indeed, external artifacts have been used as support for effective communication between providers in an ICU (Miller, Miller, Hutchison, Weinger, & Buerhaus, 2008). In addition, shared displays have been used for improving common ground in large group hospital rounds; since different members of the rounds team provided different capabilities, external artifacts were the means for joint-sense making (Xiao et al., 2008). External artifacts have also been used for planning and coordination in an emergency department (Wears, Perry, Wilson, Galliers, & Fone, 2007), in an operating room (Nemeth, Cook, O’Connor, & Klock, 2004), and amongst anesthesiologists (Nemeth et al., 2004).
Medication-related interventions. Not only are the above examples useful in showing that external artifacts support provider communication, they suggest properties necessary for an external support to be successful. According to one study, a successful external artifact is malleable (easily configured), ecological (cost-effective), widely available, and requires no special skills to use (Wears et al., 2007). A different study recommended that cognitive artifacts should at the very least be accurate, up to date, efficient, reliable, relevant, clear, and malleable (Nemeth et al., 2004). Therefore, any external artifact that will be used in medication planning should have these characteristics to support collaborative teaching and problem solving to improve adherence.

Some progress has been made in this direction. One study tested a low-literacy medication chart with minimal text and only four scheduling time slots (Cordasco et al., 2009). Compared to standard care, the intervention did not improve adherence, but it did improve self-reporting accuracy. The design of the medication tool was simple, using a matrix format with spots for the three meals and bedtime. The information for each medication listed the name (generic and brand), dose size, and, for some, the medication’s purpose represented with an icon. A pill icon, sometimes with instructions beneath, was placed in the columns that corresponded to when the medication should be taken. The number of pills represented how many should be taken, this was also written underneath each pill for redundancy. Unfortunately, the tool may not have been too clear for the patient. The use of varying colors could have affected the salience of the pill icons, and the simplification down to four specific time spots could have caused confusion. For example, two medications that were to be taken with food were put at breakfast (with a plate icon). In the same column, another pill was scheduled to be taken without food (with a plate icon crossed out). However, it is unclear as to how a patient would take two pills with food and one without all at breakfast. For the low health-literate bad medication adherence may be reinforced. Finally, this study did not use the tool as a collaborative device; instead the patient was simply given the printed schedule of their meds and a nurse explained the schedule. The patient was not active in the creation of the schedule, the tool was not malleable to their needs, and thus any issues arising related to nonadherence were not addressed.
Another study developed a pill card which primarily used symbols and icons to promote home medication scheduling and adherence (Kripalani et al., 2007). Similar to the above study, the schedule was developed by providers and given to the patient with training. However, the tool proved useful for remembering key medication information, and it was most helpful for those with low health literacy. This card also represented schedules with a matrix. The matrix had four time periods as well, but the periods were vaguer, e.g. “morning/breakfast”. The tool was clear and relevant as there was no distracting use of color, medication purpose was more explicit, and the schedule markers were actual pictures of the pills. Also the instructions were listed with the medication and not under each pill, making the tool more efficient. However, the tool was not malleable to the patient’s specific schedule nor was it used to enhance patient-provider collaboration. Furthermore, ease of using the tool and patient preferences were not evaluated.

Fortunately, there has been one study that has looked at patient-provider collaboration for medication planning. This study looked at reconciling patient and provider misunderstanding concerning the medication scheduling of an anticoagulant (Machtinger et al., 2007). The study used an external artifact that illustrated a patient's weekly drug regimen with a matrix table. The artifact was very ecological as it could be created in multiple languages and taken home with the patient once the session was over. The design was plain enough for the important information to remain clear and relevant to the patient. Even though the artifact only focused on a single medication, it improved adherence to that medication as well as patient outcomes.

The original MedTable. It would be amiss to not mention the precursor to this study (Morrow et al., 2008). In that study, a medication table (the MedTable) was developed to support communication and collaborative planning in a medication scheduling task. The scheduling task consisted of selecting daily dose taking times for a number of medications, all of which have their own instructions, e.g. take with food, take on an empty stomach, etc. The original MedTable was a matrix (see Day, 1988) in which medication information and instructions could be written in the leftmost column and schedule information could be written across the top row. Pictorial icons were used to represent typical daily events and reinforce the
patient’s prospective memory. Furthermore, appropriately captioned pictures can enhance the patients comprehension and understanding (Mayer & Moreno, 2003). After the information was written into the tool, medication scheduling is done by finding the cell that matches to the appropriate time and medication and making an "x" for each of the pills to be taken at that time. This paper artifact was simple to use (only a pen was needed), visible (large boxes for writing in information), flexible (directions were customizable), and easy to share for collaborative work.

The MedTable was tested against an unstructured aid (blank paper) with pairs of older adults acting as simulated patients and providers. For each task, the provider was given medication information and told it to the patient, who wrote it into the table. The patient also wrote their daily routine into the time slots. The MedTable proved successful in improving medication accuracy and task completion time over the unstructured aid. Furthermore, the MedTable has been used at a Peoria hospital with a provider who used the tool to help patients organize their actual medication regimens. The patients indicated that they would like to use the tool with their provider, and that it helped their medication adherence task (Conner-Garcia, Graumlich, Ellison, Morrow, & Wolf, 2008).

The design of the e-MedTable.

The next step in this process was to design and test a computer program built similarly to the MedTable. The e-MedTable was built to take advantage of the rising popularity in healthcare information technology. According to a 2009 survey, about 44% of physicians use an electronic medical record system (EMR); this number is on the rise from 30% in 2006 (Hsiao et al., 2009). Implementing an external artifact into the already existing EMRs would improve its ease of access and availability so that it could quickly become a part of the routine of a clinical visit (widely available and ecological). Finally, an electronic artifact would be more malleable as it would be customizable to a number of different patient routines.

Overall, the e-MedTable is designed to be used by any and all computer users. Some features are built to benefit older users, but the overall product was designed to be usable for any age (Schneider, Schreiber, Wilkes, Grandt, & Schlick, 2008). Although the product is meant
for collaborative use, it was implemented in a single workstation and so it does not suffer from workspace sharing issues that usually arise with collaborative software (Gutwin & Greenberg, 1998). The e-MedTable was designed to minimize mouse movement by keeping the medication selection buttons and medication scheduling buttons all in one area of the interface thereby minimizing visual search and need for fine motor control, and reducing demands on perceptual-motor and fluid abilities, age-vulnerable cognitive resources (Mead, Lamson, & Rogers, 2002; Winkelholz & Schlick, 2007). Also, scheduling buttons were used instead of checkboxes as they provided a bigger target for participants to click; and no double clicks are necessary for interaction (Hawthorn, 2000). These features of the interface were intended to accommodate age-related slowing of mental processing that has been shown to impair older adults’ use of a mouse when performing routine computer tasks (Mead et al., 2002).

The program was created to allow continual changes and backtracking without pesky pop-up windows asking the user to verify his/her choice. The hope is that the user’s limited attention will not be distracted from the task at hand (Vertegaal, Shell, Chen, & Mamuji, 2006). On the left-hand side of the program the medication information is displayed. For the most part, this information is only relevant when scheduling the specific medication. Cognitive overload in processing essential task information can happen if cognitive resources are devoted to extraneous material; to prevent this, the user is signaled by a colored box as to which medication information is of interest and essential (Mayer & Moreno, 2003).

**The Current Study**

The overall goal of the present research is to test whether the e-MedTable increases the ability of patients and providers to collaborate and develop accurate medication schedules to support adherence. As a first step, a simulated study was performed involving pairs of older adults randomly assigned to the roles of patient and provider. Older adults were chosen since they stand to benefit most from adherence-related interventions. Furthermore, if an electronic tool proved successful for older adults who are often slow to adopt new technology, the findings should generalize to younger adults, who are typically more tech-savvy. The pairs completed several medication scheduling problems using one of three collaborative artifacts.
The scheduling problems varied in levels of complexity, defined as the number of medication constraints that had to be met to develop a correct solution. Two of the tools were structured to support scheduling (the MedTable and e-MedTable), whereas the other was less structured, providing only medication information and blank space (the Medcard). The latter tool was adapted from medication cards used in area of health organizations. The primary performance measures were problem solving time, accuracy, and workload. Workload was included due to the possibility that an external tool may impact problem solving effort without affecting accuracy or time. A tool that supports efficient scheduling with little workload would be more likely to be adopted by providers. The patients also rated the usability of the external artifact.

A secondary goal of this study is to test the influence collaboration has in solving the medication problems. To achieve this, individual participants also performed the above tasks. Collaboration should influence performance and decrease workload for the tasks, especially in the complex problems.

Predictions

**Hypothesis 1.** Even though all three artifacts offer an external resource for collaboration and sharing information, the two more structured tools should reduce the cognitive demands of planning because they are structured for scheduling using a matrix that integrates medication and time information, whereas the less structured tool contains only a medication list. Matrices allow for better retention and understanding of multi-medication schedules than lists (Day, 1988; Seals & Duffy, 2005). The structured tools should allow common ground to be formed quicker and easier than the less structured tool. Therefore, participants should schedule medications more quickly and accurately when using the structured tools. In addition, the structured tools should have higher usability and lower perceived workload since the tools are designed to support collaboration and problem solving.

**Hypothesis 2.** The paper-based MedTable may support better performance than the e-MedTable due to the possibility that older adults may have trouble using computer tools. However, it is possible that any differences can be offset in actual healthcare contexts because the computer tool could more easily be integrated into healthcare information technology.
**Hypothesis 3.** Simpler problems will be easier to solve than more complex problems, as found in the previous study (Morrow et al., 2008).

**Hypothesis 4.** The structured artifacts will be more beneficial for the complex problems rather than the simple problems. The complex problems will require more cognitive effort, and the support the structured tools provide will be more evident in the complex problems.
CHAPTER 3: METHODOLOGY

Participants

144 community-dwelling older adults (60 years and older) participated in this study (age: \( M = 71, SD = 7.3 \); 64% females). Participants were paired and randomly assigned the role of patient or provider. Pairs were randomly assigned to one of the three tools (Medcard, MedTable, e-MedTable), totaling 24 pairs per group. The participants were screened to ensure that they were native speakers of English, had no obvious physical or cognitive impairments that could restrict participation (e.g. stroke in the last three years, currently receiving chemotherapy or radiation), and regularly use a computer at least weekly. Those who had worked as a health care professional were excluded from the study because their domain knowledge of medication and might influence performance.

In addition to pairs, data were collected on a small group of individuals (\( N = 13 \): 5 MedTable, 4 e-MedTable, 4 Medcard) in order to explore the impact of collaboration on the medication scheduling task. Unfortunately, there was not enough time to run enough individuals per tool group in order to investigate the impact of tool type on individual versus collaborative problem solving.

Ability measures. The participants were asked to fill out a short demographic survey that asked for the individual’s occupation, computer usage, self-assessed health score, and medications currently prescribed, among other things. Education was measured via an ordinal scale from 1 (less than 8 years completed) to 7 (obtained advanced degree). Cognitive abilities were measured because they may influence problem solving performance. General knowledge and verbal ability were measured by the Advanced Vocabulary Test from the ETS Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, & Harman, 1976). Speed of mental processing was measured by two comparison tasks, Letter Comparison and Pattern Comparison (Salthouse, 1991). In these tasks, participants are given thirty seconds to determine if pairs of letter strings or patterns are identical or different. Speed of processing like working memory is considered a “fluid ability” that is important for proficient information processing.

Error! Reference source not found. shows the demographics for the three tool conditions. The three groups did not significantly differ in age, education, or vocabulary scores.
However, the speed of processing was significantly higher ($p < .05$) for the group that used the e-MedTable than the other two groups. Speed of processing was used as a covariate in the analysis of problem solving time. Table 2 presents the demographics for the individuals. Individuals also had significantly lower speed of processing scores than the pairs.

**Medication Scheduling Problems**

Participants were asked to complete medication problems that varied in complexity. Six problems were created by the research team, three simple and three complex. All medication problems consisted of four medications presented with name, purpose, size of dose, frequency, special instructions (take at meals, on an empty stomach, etc.), and also a specific, rigid patient routine. Although the medications were fictional, the instructions and names were created by looking through an online database of existing medications (www.rxlist.com). The problems were then validated by a physician who routinely prescribes medication. The patient routine was created with mealtimes, wake-up, bedtime, and the patient’s work schedule including breaks. The work schedule information was not documented on any of the tools, including the structured tools. The patient’s day always consisted of 16 hours, but the times of key events varied for each problem. The participants were told that the patient routine was not flexible and should not be adapted to mirror their own actual routine.

In Morrow et al. (2008), problem complexity was defined by the number of medications and the familiarity of the patient’s schedule - a night work schedule was considered more complex because it was less familiar. However, in the present study the number of medications was held constant at four in each problem, and the patient routines were all typical. Problem complexity was defined in terms of the size of the solutions space (schedules that fit constraints). Complex problems had more constraints associated with the medication and patient routine information, and fewer feasible solutions that met these constraints. The complex problems also had co-occurrence constraints between medications. Therefore, the complex problems should require more cognitive effort to search the problem domain to find a feasible solution (Newell & Simon, 1972). The problems are given in the Appendix A.
Materials

**e-MedTable development.** The e-MedTable was developed over several months, going through several iterations. The version of the tool that was evaluated in the present study can be seen in Figure 1. The program was developed in Microsoft Access 2007 with Visual Basic for Applications, which allowed for rapid development of the prototype. The design goal was how to incorporate the successful functionality found in the original paper tool into an easy to use computer interface. The elements of the original paper tool that should be incorporated were: a) a location for medication information, b) a place for the patient’s routine to be displayed, and a matrix or table for scheduling the medications. However, in this study, the medication information would be pre-populated onto the tool, rather than having the patient type it into the tool. This differs from the previous study in that the patient was responsible for writing the medication information onto the paper MedTable when it was dictated to them from the provider (Morrow et al., 2008). Thus, the content was already determined by the MedTable, but how to present that content in a user-friendly way was not.

The easiest way to figure out how to structure the content was to go through the steps it would take for a user to solve one of the medication problems. The steps to solving a problem are:

1. Read the medication information.
2. Choose a medication to schedule from the four given.
3. Read or reread the medication instructions for the chosen medication.
4. Select the times that the chosen medication should be taken.
5. See how those selected times fit into the entire schedule.
6. Repeat previous steps until all medications are scheduled.

The first decision was to figure out where the medication information should be located (necessary for steps 1 and 3). We eventually decided to place it on the left-hand side (Figure 1, Box A) where it was easy to read as the information was non-interactive and should not take up precious screen real-estate elsewhere.

Another major decision was to determine how to interact with the medication scheduling table (Figure 1, Box E). The scheduling table is the matrix that synthesizes time with...
medication into a viewable schedule. The concern was about how to get medication into that table (step 4). Ideally, a multi-touch screen would be used for this manipulation instead of a mouse (Murata & Iwase, 2005), but touch-screens are costly, and they would place an additional burden on health care clinics reducing their likelihood of adopting a program like the e-MedTable. Therefore, given that the older adults would be using a mouse, what would be the best way for them to enter medication times into the scheduling table? A couple of options were considered: a) drag-and-drop, b) direct manipulation through clicking, and c) indirect manipulation. A drag-and-drop interface would require the patient to drag a medicine icon into the table, but this would not be best for older adults who typically lack fine motor control (Mead et al., 2002). The second option would involve the participant clicking on the desired cell in the table and typing input. However, since there would be 64 possible cells for scheduling (16 hours x 4 medications), clicking the correct cells would also require fine motor control. Therefore, for the sake of the target users, it was decided that indirect manipulation would be the best input method. This meant that the user could click elsewhere other than the table, and the program would place the information into the correct cell in the matrix.

Therefore, given a specific medication, all the user had to do was click on a checkbox for a specific time to schedule that medication at that time. However, due to the rigidity of checkbox sizes in Microsoft Access (“one size fits small”), buttons for inputting medication scheduling times were chosen (Figure 1, Box D). The buttons were much larger than the checkboxes and should minimize the perceptual and motor resources required to target and click on the buttons (Murata & Iwase, 2005). Clicking on a time button places a check on the button and populates the appropriate cell in the medication matrix with x’s corresponding to the number of pills in a dose. For example, if Hydrapaque is the selected medicine and a single dose is 2 pills, clicking on the box above 1 PM would place “xx” in the cell of the table that corresponds to the Hydrapaque row and the 1 PM column.

This decision for indirect manipulation of the table influenced how medications were selected (step 2). To minimize mouse movement, a combination-box for choosing medications was placed above the main scheduling buttons (Figure 1, Box B). When not in use, combo-boxes
take up little space, but when being used they can expand to as large as needed. The box was labeled “Select Medicine” to clarify its function.

With the essential design finished, some decisions were made to reinforce the user’s choices. When a medication was selected in the combo-box, its corresponding medication information on the left and its row in the scheduling table would be highlighted. Ideally, the highlight would be the same for both and be a salient color such as orange, but Microsoft Access did not allow the row selection color to change from the default grey. The grey row did stand out in the white table, but it did not match the orange used to highlight the medication information. Also, similar to the original MedTable, icons were used to illustrate major events in the patient’s daily routine (Figure 1, Box C) (Morrow et al., 2008). Finally, it was necessary to add some administrative buttons (Figure 1, Box F). The “Save” button is used by the patient when they wish to save their completed schedule. The “Reset” button clears medication scheduling table without saving after confirming with the user. The “Close” button quit the program without saving and cleared all progress.

During the development, the research team decided that the users’ interactions with the interface should be recorded to learn more about possible usability problems as well as to acquire more information how participants used the interface to schedule the medications. Screen capture software allowed click-level data to be captured to determine which functions were successfully implemented or not. Morae (http://www.techsmith.com/morae.asp) was chosen as it captured video and audio and came with analysis tools. This data will also be used in a future study on the tool’s impact on problem solving.

Throughout the development of the e-MedTable, there was periodic informal user testing. Users included undergraduates, other researchers, and university employees. These users’ comments influenced the evolution of the interface, including turning the check-boxes into check buttons, and adding color to highlight what medicine was scheduled. After the e-MedTable reached its final form, it was tested in a pilot study involving two older adults from the community. Since no major design flaws became evident from the pilot study, the experiment was started.
Comparison with other tools. The e-MedTable departs from the MedTable used in Morrow et al. (2008) in that the medication information is already pre-populated onto the interface. This was to simulate the likely event that an electronic intervention would import medication information from an existing database, perhaps one found in an EMR. Furthermore, the e-MedTable displays a full patient's daily schedule, hour by hour for a 16 hour day. The decision to use hourly rather than more general temporal categories on the interface was based in part on findings that low health literacy patients better understand medication instructions when dose times are more explicit and specific (Wolf et al., 2007). Personalizing the patient’s schedule could easily be done in a clinical setting by asking the patient about their typical routine. Because these changes were deemed to be significantly different from the previous study, the MedTable used in this study was also adapted to reflect these modifications and better match the e-MedTable. Although the tool remained on paper, the only writing now necessary to complete a schedule using the MedTable would be the x’s in the cells that signal a medication should be taken at the given time, similar to clicking the medication time buttons on the e-MedTable. Both tools included icons for meals and bedtimes similar to the original MedTable (Morrow et al., 2008).

Because these two tools included both medication information and the patient’s daily schedule explicitly organized into a table, these tools were considered structured tools. They provide a shared external workspace where schedule constraints are visible to both patient and provider to support collaborative planning. They contrasted with the third tool tested in this study, the medication card ("Medcard"). It lists medication name, purpose, dose, frequency, and directions for each medication. The Medcard was modeled after an actual medication reconciliation card currently used in a local healthcare network. However, because the intention of a medication card is to help patients maintain a complete list of medication information, the tool is not structured to support communication and collaborative planning in a medication scheduling task. Only blank white space on the tool is provided for planning.
Procedure

After obtaining consent, participants filled out a demographic survey and completed the Advanced Vocabulary test (Ekstrom et al., 1976). They were then led into the experiment room and seated at a table across from each other. At this point, the participants were notified of their roles and given general instructions about the task. Although the patient and provider worked together to create the schedule, the patient was responsible for documenting the schedule onto the tool, using either a computer mouse (e-MedTable) or a pen (MedTable or Medcard). At the start of each problem, the patient received a sheet of paper with the patient routine information, and the provider received a sheet with the instructions for prescribing the four medications. The medication information given to the provider was similar to what was on the three tools; the difference was that the provider also had information that could answer the question "why?" whereas the tool lacked this. This information was provided to encourage the provider to be more involved in creating the schedule. The participants were given 1 minute to look over the information and familiarize themselves with it. Next, the patient was given the tool, and the pair was told to begin creating a schedule that was consistent with the patient and medication constraints. Task completion time was measured with a stopwatch. A time limit of 15 minutes was imposed for each problem, but participants ran out of time in less than 2% of the trials (5 complex problems).

All groups were given the same two practice problems in the same order, one simple and one complex. The practice problems were given to familiarize the pair with the tool and the task, and to minimize learning effects across the four experimental trials. The four experimental trials were blocked by complexity (2 simple and 2 complex), and the order of the problems within each block, as well as the order of the blocks, was counterbalanced across participants in each tool group.

When the problem was completed, the patient was prompted by the experimenter to read aloud the schedule. This was to check that the patient understanding of the schedule, and to allow the pair one last chance to correct any mistakes. If a mistake was caught during this read-back, the additional time to correct the error was added to task completion time. After the read-back, both the patient and provider separately filled out the NASA Task Load Index (NASA-
The NASA-TLX assesses six factors of subjective workload: mental demand, physical demand, temporal demand, self-appraised performance, effort, and frustration. The NASA-TLX was used in the practice problems as well to help the participants anchor themselves on the scale. Morrow et al. (2008) found a significant increase in perceived workload for the more complex problems and for patients versus providers.

After the four trials were completed, the patient completed a tool usability survey, since only the patient used the tool (Brooke, 1996). The survey asked seven questions about the usability of the tool (Appendix C). Both participants also filled out a Partner Awareness survey to measure perceived collaboration during problem solving. The survey is derived from questions taken from the Activity Awareness Questionnaire (Convertino, Mentis, Rosson, Slavkovic, & Carroll, 2008). In the survey, the participant is given 10 statements and they are asked to rate on a 5 point Likert scale whether they disagree or agree with the statement (Appendix B).

After the surveys were completed, the participants completed the Letter and Comparison Tests (Salthouse, 1991). The session concluded with a brief survey called the Tool Preference Survey. The survey asks the participant if they are familiar with medication scheduling. If so, it asks what methods have been used – such as verbal instruction, calendars, pill organizers, etc. – and whether a provider helps with the scheduling. The survey then asks how the tool used in the trial compares in usefulness and helpfulness to their usual method of care. All participants were audio recorded for later analysis.

The only differences in the above procedure for the individual participants are that they were given both sheets of paper in the self-study period, and they did not fill out a partner awareness survey.

**Dependent Variables**

The dependent variables can be divided up into the following categories: a) problem solving performance, b) collaborative processes, c) tool usability, and d) workload. Problem solving performance includes the measures of solution accuracy, solution completion time, and solution optimality. Collaborative processes were measured using the Partner Awareness
survey. Tool usability was measured with the System Usability Scale (Brooke, 1996) and the tool preference questionnaire. The specific usability of the e-MedTable was assessed using the click behavior data captured with Morae. Workload was measured with the NASA-TLX (Hart & Stavenland, 1988). Workload is in a separate category in that it is probably affected by tool usability, collaboration, and performance, the other three categories.

**Solution accuracy.** Accuracy for each problem was measured by the proportion of the number of problem constraints met by the solution. These constraints included: correct number of doses, appropriate medication taking times, patient routine restrictions, and medication co-occurrence restrictions. For the simple problems, there were 18 constraints. The number of constraints for the complex problems was 22 or 24, depending on the particular problem. For example, for the following instructions: “Take 3 pills of Amelorine twice a day with a meal,” there were four:

1. Was Amelorine scheduled?
2. Were 2 doses scheduled?
3. Was dose 1 with a meal?
4. Was dose 2 with a meal?

When a constraint is met, the pair scored a 1; if not, a 0. For the dose questions (3 and 4), solutions with too few doses received a 0 for each missed dose. If there were too many doses– in this example, confusing dose with frequency would result in three separate drug taking times instead of two – the result was averaged. For instance, to answer question 4, the grader looked at dose 2 and dose 3. If dose 2 and dose 3 were at a meal, the group received a score of 1. If only one of the doses was at a meal, the group received a score of 0.5. If neither dose was at a meal, the score was 0. Two graders independently scored 6 different experimental trials (24 scheduling problems) with 99% inter-grader agreement.

**Solution time.** Completion time was measured from when the tool was given to the pair to when the pair indicated to the experimenter that they had completed scheduling or until the 15 minute time limit was reached, then the read-back started. If the pair revised a solution during the read-back, the time for revision was added to solution time.
**Solution optimality.** Solution optimality was defined on two dimensions: spacing between doses of the multiple-daily dose medications and number of medication taking times. Regular and even dose spacing is necessary to maintain a medication’s level of effectiveness by keeping consistent levels of the drug in the patient’s system. Minimizing number of medication times is helpful in remembering a schedule; the fewer times medications are taken, the less opportunity there is to forget. Indeed, adherence is better with fewer medication times (Osterberg & Blaschke, 2005). All optimal scores are between 0 and 1, thus they can be seen as percentages of achieved optimality.

To begin, an optimal solution for each problem was created by the research team. The optimal solution met all of the problem constraints and focused on meeting the two optimal factors as best as possible. For instance, with the previous example, optimal spacing for Amelorine would be to put dose 1 (D1) with breakfast and dose 2 (D2) with dinner. Therefore, the optimal dose spacing for that problem would be the number of hours between those two meals. If there were more than two doses, an optimal spacing was found for each time period between the doses (i.e. between D1 and D2, between D2 and D3, etc.). Of course, optimal spacing is not possible for medications with a single dose.

The optimal (minimal) number of medication times for a schedule was found by grouping medications as much as possible. For example, the medication problem with Amelorine also contained Stezapine, with which 1 pill was taken three times a day with meals. An optimal solution would be to take 2 medications at breakfast and dinner and lunch would have one medication scheduled. Therefore, if the problem was only these two medications, the optimal number of medication times would be 3. However, in all the trials this number was either 5 or 7, independent of problem complexity.

Once an optimal number was determined, an optimal score was obtained using the following formula:

\[
\text{Optimal Score} = 1 - \frac{|\text{Actual Num} - \text{Optimal Num}|}{\text{Optimal Number}}
\]

This formula penalized equally the participants who spaced doses too far apart or too close. Likewise, this penalized those pairs who had less than the minimal number of medication taking times, which was only possible to accomplish by violating constraints.
Only solutions with the correct number of doses for each medication were scored for optimality, which removed 13% of the problems from analysis. The reason for this was that both factors of optimality would be influenced by too many or too few doses. Dose spacing cannot be calculated for missing doses, nor could a reasonable argument be made to average out extra doses. Furthermore, extra or missing doses would likely affect the total number of medication taking times.

Optimal scores were created for each problem solution. For medication taking times, this was trivial since only one score existed for each problem. However, for consistent dose spacing, first the inter-dose optimal scores had to be averaged for each medication. This process is illustrated in Figure 2 for a problem with one medication with 2 doses, one with 3 doses, and one with 4 doses (the single dose med was omitted from analysis).

**Collaborative processes.** The Partner Awareness survey was created by taking 10 questions from the list of 49 questions created by the CSCL lab at Penn State (Convertino, Mentis et al., 2008). These questions covered a broad range of the collaborative process including perceived performance and quality of collaboration, communication and common ground, shared practices, and interpersonal awareness. The survey was administered after all of the trials were completed, so the survey reflected the overall collaborative process. Though several of the questions were correlated in previous studies with one another (Convertino, Mentis et al., 2008), there is no established composite of the scores. The questions were divided into their correlative cluster. The survey can be found in the Appendix B.

**Tool usability.** The Usability questionnaire was developed by taking seven questions from the ten questions of the System Usability Scale (SUS) (Brooke, 1996). The three questions were omitted because they were only relevant to computer tools. For example, it would be difficult for a participant to determine the consistency and functional integration of a paper tool as well as whether they needed the support of a technical person. A composite of the seven questions was created according to Brooke's methods (higher scores are better). The Usability survey given to the participants is in the Appendix C.

The Tool Preference questionnaire also included two questions related to tool usability. Both participants completed this survey. The questions asked the participants how helpful
The tool used in the trial compared to their usual care methods for scheduling. The questions were 3-point Likert, with the following scale: 1) Not at all, 2) same as usual care, 3) more helpful (useful).

**Subjective workload.** Subjective workload for each problem was measured using the NASA-TLX (Hart & Stavenland, 1988). The index consists of six subjective scales (0 to 100): mental demand, physical demand, temporal demand, performance, effort, and frustration. The measure asks the participant to mark along a segmented line to rate the degree of each factor from very low to very high (except perceived performance, which goes from perfect to failure). The scales are structured that small scores represent minimal subjective workload and perceived performance as perfect.

**Usability errors on the e-MedTable.** As mentioned previously, the usage of the e-MedTable was captured with software known as Morae. Morae captured the time and location of all of the users’ clicks on the interface. This provides extremely helpful insight into how the users interacted with the software. This data helps us to understand what they did not understand about interacting with the interface and what aspects of it were clunky. Finding out where the design went wrong will inform future software developed after the e-MedTable.
Figures and Tables

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

Figure 2: How an optimal score regarding dose spacing was calculated for a problem.
Table 1: Mean (and Standard Deviation) Values for Demographic and Individual Difference Variables by Condition (N = 24 per group)

<table>
<thead>
<tr>
<th>Variable</th>
<th>e-MedTable</th>
<th>MedTable</th>
<th>Medcard</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>70.4 (6.91)</td>
<td>70.9 (7.43)</td>
<td>72.0 (7.61)</td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Education (%)</td>
<td></td>
<td></td>
<td></td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Graduate High School</td>
<td>10.4</td>
<td>14.6</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>Some College</td>
<td>31.3</td>
<td>12.5</td>
<td>29.1</td>
<td></td>
</tr>
<tr>
<td>Graduated College</td>
<td>20.8</td>
<td>27.1</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Advanced Degree</td>
<td>37.5</td>
<td>45.8</td>
<td>41.7</td>
<td></td>
</tr>
<tr>
<td>Self-rated Health Score</td>
<td>5.4 (1.0)</td>
<td>5.5 (1.0)</td>
<td>5.5 (1.6)</td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Mean Number of Meds</td>
<td>3.8 (5.5)</td>
<td>3.4 (3.1)</td>
<td>3.4 (2.3)</td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Vocabulary Score</td>
<td>10.6 (4.2)</td>
<td>10.8 (4.0)</td>
<td>11.7 (4.1)</td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Speed of Processing Score</td>
<td>11.8 (2.2)</td>
<td>10.9 (1.8)</td>
<td>10.9 (1.9)</td>
<td>&lt; .05</td>
</tr>
</tbody>
</table>

Table 2: Mean (and Standard Deviation) Values for Demographic and Individual Difference Variables by Collaborative Condition. The p-values are the result of a 2-sided t-test for Equality of Means.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pairs (N = 144)</th>
<th>Individuals (N = 13)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>71.1 (7.3)</td>
<td>71.6 (6.8)</td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Education (scale)</td>
<td></td>
<td></td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Graduate High School</td>
<td>9.7</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>Some College</td>
<td>24.3</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td>Graduated College</td>
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<td>23.1</td>
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</tr>
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<td>Advanced Degree</td>
<td>41.7</td>
<td>46.2</td>
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<tr>
<td>Self-rated Health Score</td>
<td>5.5 (1.2)</td>
<td>5.1 (1.6)</td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Mean Number of Medications</td>
<td>3.5 (3.8)</td>
<td>3.0 (3.1)</td>
<td>&gt; .10</td>
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<tr>
<td>Vocabulary Score</td>
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<td>9.7 (4.5)</td>
<td>&gt; .10</td>
</tr>
<tr>
<td>Speed of Processing Score</td>
<td>11.2 (2.0)</td>
<td>10 (2.0)</td>
<td>&lt; .05</td>
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</table>
CHAPTER 4: RESULTS

An alpha level of .05 was used for all statistical tests. Even when tool effects were not significant, pairwise comparisons were still conducted to test the specific predictions about tool differences (Keppel, 1982). Comparisons were made using the Least Significant Difference test.

Problem Solving Performance

The problem solving variables of accuracy, completion time, and optimality were analyzed by a Tool Group (MedTable, e-MedTable, Medcard) x Problem Complexity (Simple, Complex) ANOVA, with Complexity as a repeated measure.

Problem solving accuracy. As can be seen in Table 3, accuracy was extremely high for all tool groups. Indeed, the main effect of tool was not significant, $F(2, 69) = 2.14, p > .10, \eta_p^2 = .058$. However, the effect of complexity was significant, with simple problems scheduled more accurately than complex problems (S = .986, C = .962), $F(1, 69) = 20.8, \eta_p^2 = .231$. The Tool x Complexity interaction was not significant, $F(2, 69) = 2.20, \eta_p^2 = .060$. Despite the nonsignificant tool effect, planned comparisons were performed to test predictions related to differences between tool conditions. Accuracy was greater in the MedTable ($M = .980$) than in the Medcard ($M = .965$) ($p < .05$), with no significant difference between the e-MedTable and the other two tools ($p > .10$).

Problem solving time. Because the tool groups differed in mean speed of processing (see Table 1), a correlation analysis using Pearson’s coefficient was performed with speed of processing, accuracy, and completion. Although accuracy and speed of processing were not correlated, completion time was inversely related to speed of processing, $r(72) = -.40, p < .01$. Not surprisingly, participants with faster speed of processing (higher speed of processing score), also finished the medication problems more quickly. Therefore the mean speed of processing score for each pair was used as a covariate in the complexity (2) by tool (3) ANOVA for solution time. The effect of complexity was not significant, $F(1, 68) = 2.5, p > .10, \eta_p^2 = .036$. Tool, $F(2, 68) = .14, p > .10, \eta_p^2 = .004$, and the interaction, $F(2, 68) = .62, p > .10, \eta_p^2 = .018$, were not significant. Without the covariate, there was only a significant effect of complexity (S = 233, C =
497), $F(1,68) = 15.7, p < .001, \eta_p^2 = .188$. Planned comparisons showed no difference in any of the tools ($p$’s > .10).

**Problem solution optimality.** Optimal spacing of doses was influenced by problem complexity, with more optimal spacing for the simpler problems ($S = .90, C = .79), F(1,66) = 4.50, p < .001, \eta_p^2 = .429$. The tool effect and tool x complexity interactions were not significant, $F(2,66) = 2.09, p = .131, \eta_p^2 = .060$ and $F(2,66) = 1.45, p = .242, \eta_p^2 = .042$, respectively. However, planned comparisons showed that using the MedTable ($M = .87$) marginally improved the optimal spacing over the Medcard ($M = .82), p = .052$. All other comparisons were non-significant.

Similar to optimal dose spacing, the minimizing medication times optimality dimension was influenced by problem complexity, with fewer scheduled times for the simpler problems, $F(1,66) = 18.83, p < .001, \eta_p^2 = .222$. Again, the tool and tool x complexity interaction effects were not significant, $F(2,66) = 1.77, p > .10, \eta_p^2 = .051$ and $F(2,66) = .97, p > .10, \eta_p^2 = .029$, respectively. The planned comparisons showed that the MedTable ($M = .95$) marginally helped minimize the medication taking times over the Medcard ($M = .92$), $p = .094$. All other comparisons were non-significant.

A truly optimal schedule would be one in which medications were both evenly spaced and taken as few times per day as possible. Indeed, participants appeared to strive to meet both factors for the simple problems because the minimizing time and dose spacing optimality scores were correlated, $r(72) = .26, p < .05$. For complex problems, there was no correlation. Therefore a final analysis was done on a composite of the average of the two optimality factors. Once again, more complex problems were less likely to be optimal ($S = .93, C = .85), F(1,66) = 60.96, p < .001, \eta_p^2 = .480$. The main effect of tool was now significant for the composite measure, with participants creating more optimal schedules when using the structured tools $F(2,66) = 3.63, p < .05, \eta_p^2 = .099$. The interaction was not significant, $F(2,66) = 2.02, p > .10, \eta_p^2 = .058$. The pairwise comparisons revealed that the MedTable ($M = .91$) yielded significantly more optimal schedules than the Medcard ($M = .87$), ($p < .05$). The e-MedTable ($M = .90$) was also marginally better than the Medcard ($p = .051$). There was no difference between the two structured tools ($p > .10$).
Collaborative Processes: Partner Awareness

Data reduction strategies were first tried to simplify analysis of this measure. The ten questions for the Partner Awareness survey fell into a number of different analysis clusters according to Convertino et al. (2008). These clusters included: shared practices (Q1 and Q2), quality of collaboration (Q4 and Q5), communication and common ground (Q8 and Q9). The remaining four questions were independent of these and each other (Convertino, Mentis et al., 2008). A principal components analysis was done on responses to all 10 questions in the present study. However the results showed that at least three factors were needed to explain only half of the data, and these factors required both positive and negative weightings of the 10 questions. Therefore, the items that were correlated into a cluster were averaged, and the remaining questions were untouched. Therefore, seven items were analyzed using a Role x Tool ANOVA.

The results from these seven analyses can be seen in Table 4. There were no significant tool- or role-related effects for the seven items (p’s > .05). Only two of the clusters showed a marginally significant effect. In regards to the quality of the collaboration, the pairs were marginally influenced by their tool (p = .07). The pairwise comparison shows that there was a significant difference between the e-MedTable and the Medcard conditions (p < .05). The participants in the e-MedTable thought that they had collaborated better than those who used the Medcard. The other marginally significant main effect was role in regards to communication and common ground. The patients thought that they had achieved common ground better than their partner, providers. Pairwise comparison of tools in this factor shows that there was a marginally significant difference between how much better the e-MedTable users rated their communication over the users of the Medcard (p = .07). To sum up, there was very little evidence that collaborative processes were influenced by type of tool.

Tool Usability

System usability scale. A one-way ANOVA was used to test the usability differences among the three tools. The SUS composite revealed that there was a significant effect of tool on usability, \( F(2, 69) = 4.34, p = .017, \eta_p^2 = .112 \). The pairwise comparisons reveal that the
participants found the MedTable ($M = 61.4$) significantly easier to use than the Medcard ($M = 52.3$), $p = .005$. The e-MedTable ($M = 57.6$) was also marginally more usable than the Medcard ($p = .09$). Interestingly, the e-MedTable was not rated as more difficult to use than the paper-based MedTable by these older participants ($p > .10$).

**Tool-Preference questionnaire.** The Tool-Preference questionnaire asked two questions regarding the usefulness and helpfulness of the tool used in the study compared to the method that participants actually used to schedule and organize medication taking in their daily life. Some of the data (11%) were excluded from analysis because participants either stated that they did not schedule medications or that their current medication required minimal scheduling (number of medications: $M = 2.5$, $SD = 1.5$). The answers from the remaining participants ($N = 102$, number of medications: $M = 3.8$, $SD = 4.2$) were tested using a chi-square. There was a significant effect of tool for the question regarding the helpfulness of the tested tool, $\chi^2(4, N = 102) = 11.53$, $p < .05$. However, there was no significant effect of tool regarding the usefulness of the tested tool, $p > .10$. The values for the tools can be seen in Table 5 and Table 6

**Subjective Workload**

As mentioned previously, the NASA-TLX is a six question survey. A principal components analysis was first conducted on the six items in order to reduce the complexity of the data. For both levels of complexity, the six items loaded on one factor that accounted for more than half the variance, simple (59.2%) and complex (58.1%). The factor loadings (Table 7) were used to create TLX composites for both levels of complexity. The TLX composites were tested with a Tool x Role x Complexity ANOVA with Problem Complexity as a repeated measure. The effect of complexity on workload was significant, with perceived workload higher for the more complex problems ($S = 74.6$, $C = 125.7$), $F(1,138) = 162.3$, $p < .001$, $\eta_p^2 = .540$. The effect of tool was marginally significant, $F(2, 138) = 3.01$. $p = .053$, $\eta_p^2 = .042$. The pairwise comparisons suggested that participants created the schedules more easily when using the two structured tools; subjective workload was lower for the MedTable ($M = 93.0$) and e-MedTable ($M = 92.7$) groups compared to the Medcard ($M = 114.8$), $p$’s < .05. The effect of role on workload was not significant, suggesting providers and patients experienced similar levels of
workload when creating the medication schedules, $F(1, 138) = .04$, $p > .10$, $\eta_p^2 = .000$. The tool x complexity interaction and tool x complexity x role interactions were not significant.

**Effect of Collaboration on Planning**

**Problem solving time, accuracy, and optimality.** To explore the effects of collaboration on problem solving, we compared the problem solving performance of pairs and individuals. Analyses were exploratory, given the small number of individuals. The t-values reported were corrected when variances were significantly different. The means of the problem solving three measures for both problem levels are shown in Figures 3 and 5. For simple problems, there was not a significant difference in problem solving time between the pairs and individuals, $t(83) = -1.60$. However, pairs were marginally more accurate than the individuals, $t(13.45) = -2.05$, $p = .06$. For complex problems, individuals finished the problems more quickly than the pairs did, $t(83) = -2.69$, $p < .01$. However, when it came to accuracy, there was no significant difference between individuals and pairs, $t(83) = -1.63$. For either level of complexity, collaboration did not show any significant effect on creating an optimal schedule. Thus, there is some evidence that pairs were slower, but somewhat more accurate than individuals.

**Subjective workload.** Subjective workload related to problem solving for pairs and individuals was compared in two ways. First, the individuals’ workload scores were compared to the patient’s scores in each pair, because the patient was most responsible for creating the schedule in the collaborative condition and thus task requirements were most comparable to the individuals (see Table 8). For both levels of problem complexity, patients in the pairs reported lower workload than the individuals, $t(83) = 2.38$, $p < .05$ for simple, and $t(83) = 2.15$, $p < .05$ for complex. Second, individuals’ workload scores were compared to the average workload for each the pair. The results were similar, with lower workload for pairs for both simple and complex problems, $t(83) = 2.74$, $p < .05$ (simple) and $t(83) = 1.77$, $p = .098$ (complex).

**e-MedTable Errors**

From the screen capturing software, the participants’ clicks on the e-MedTable were captured in order to analyze usability issues with the interface and to understand how the tool...
affected problem solving. These clicks were coded to analyze the processes involved in problem solving in preparation for a future study that will focus on evaluating a cognitive model of problem solving. Of most relevance to the present study are errors related to usability of the interface. These usability errors were clicks on the interface that appeared to reflect confusion about how to interact with the interface, and not clicks related to solving the problem with the interface. These included clicks on the medication information on the left, on the scheduling table, on the icons, or anywhere else that is not the combo-box or the scheduling check-boxes. These clicks are irrelevant to the program itself because it does not register them, but they do offer insight into what are the most likely confusing aspects of the program. Error clicks were categorized into four categories:

1. Clicks on the medication information box
2. Clicks on the medication names in the medication table (left-most column)
3. Clicks on the scheduling icons
4. Clicks on the table – either a specific cell or the time labels on the columns, just not the cells in the first column (error 2)

These click errors can be seen as representing two misunderstandings. Errors 1 and 2 reflect confusion about how to change to a specific medication. Rather than clicking the combo-box, the user tried to navigate elsewhere. The other two errors reflect a misunderstanding of how to schedule the medication at a specific time. Clicking on the table or the headings of the table do not schedule the medication at the time clicked; only the schedule buttons do this function.

Of the more than 3000 clicks made in the practice and trial problems, less than 150 of all the clicks were interface errors (4.7% error rate across all 24 pairs in the e-MedTable condition). When the practice problems are ignored, the error rate drops to 2.9%. Considering that the average user only made 90 clicks to complete all four trials, users typically made less than three error clicks once they became familiar with the interface. Including the practice trials, this number jumps to 6 error clicks per user in all six trials. Figure 6 presents the number of errors in each category by problem complexity. What is evident is that the most common type of error
was clicking on the table for scheduling purposes. This occurred 33 times throughout the trials. All the other aforementioned errors only occurred seven to eight times apiece.

This may actually overestimate interface click errors; we assume that these clicks were intentional and resulted from a mismatch of the program’s functioning and the user’s mental model. Some of the errors could simply result from poor sensory motor control and be unintentional. Indeed, six clicks were on blank spots on the interface and could not reflect a misinterpretation of the interface. Finally, it is also possible that some error clicks were intentional but did not reflect a misconception, such as clicks on medication box that were done to reinforce what the patient was saying to their partner (that is, to communicate rather than schedule the medication).

**Figures and Tables**

**Figure 3:** The mean values of accuracy for individuals and pairs by problem complexity.
**Figure 4:** The mean values of completion time for individuals and pairs by problem complexity.

**Figure 5:** The mean values of optimality scores for individuals and pairs by problem complexity.
Figure 6: The number of error clicks by type and problem complexity.

Table 3: Mean (and Standard Deviation) Values for Problem Solving Measures

<table>
<thead>
<tr>
<th>Problem Complexity</th>
<th>Tool</th>
<th>Accuracy, % Correct M (SD)</th>
<th>Time, seconds M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>e-MedTable</td>
<td>99.0 (2.1)</td>
<td>230 (79.6)</td>
</tr>
<tr>
<td></td>
<td>MedTable</td>
<td>98.5 (2.3)</td>
<td>249 (86.6)</td>
</tr>
<tr>
<td></td>
<td>Medcard</td>
<td>98.4 (2.2)</td>
<td>219 (67.2)</td>
</tr>
<tr>
<td>Complex</td>
<td>e-MedTable</td>
<td>96.2 (4.1)</td>
<td>480 (156.7)</td>
</tr>
<tr>
<td></td>
<td>MedTable</td>
<td>97.6 (4.1)</td>
<td>501 (156.6)</td>
</tr>
<tr>
<td></td>
<td>Medcard</td>
<td>94.7 (4.7)</td>
<td>509 (141.8)</td>
</tr>
</tbody>
</table>

Table 4: Results from Tool x Role ANOVA on Partner Awareness Questions. The underlined values show marginally significant effects.

<table>
<thead>
<tr>
<th>Measure (Cluster)</th>
<th>Tool F(2, 138)</th>
<th>p</th>
<th>Role F(1, 138)</th>
<th>p</th>
<th>Tool*Role F(2, 138)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 &amp; Q2 (Shared Practices)</td>
<td>0.70</td>
<td>0.49</td>
<td>0.04</td>
<td>0.84</td>
<td>0.40</td>
<td>0.78</td>
</tr>
<tr>
<td>Q4 &amp; Q5 (Quality of Collaboration)</td>
<td>2.66</td>
<td>0.07</td>
<td>1.91</td>
<td>0.17</td>
<td>0.11</td>
<td>0.98</td>
</tr>
<tr>
<td>Q8 &amp; Q9 (Common Ground)</td>
<td>1.67</td>
<td>0.19</td>
<td>3.72</td>
<td>0.06</td>
<td>0.17</td>
<td>0.84</td>
</tr>
<tr>
<td>Q3 (Development)</td>
<td>1.94</td>
<td>0.15</td>
<td>2.42</td>
<td>0.12</td>
<td>1.26</td>
<td>0.29</td>
</tr>
<tr>
<td>Q6 (Performance)</td>
<td>0.43</td>
<td>0.65</td>
<td>1.43</td>
<td>0.23</td>
<td>0.11</td>
<td>0.90</td>
</tr>
<tr>
<td>Q7 (Satisfaction)</td>
<td>0.06</td>
<td>0.95</td>
<td>0.09</td>
<td>0.76</td>
<td>0.19</td>
<td>0.83</td>
</tr>
<tr>
<td>Q10 (Interpersonal awareness)</td>
<td>0.23</td>
<td>0.80</td>
<td>1.53</td>
<td>0.22</td>
<td>0.16</td>
<td>0.86</td>
</tr>
</tbody>
</table>
Table 5: Frequency of Response by Tool for the First Question (Helpfulness) of the Tool Preference Measure

<table>
<thead>
<tr>
<th>Tool</th>
<th>Less Helpful</th>
<th>Equally Helpful</th>
<th>More Helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>e-MedTable</td>
<td>16%</td>
<td>45%</td>
<td>39%</td>
</tr>
<tr>
<td>MedTable</td>
<td>11%</td>
<td>47%</td>
<td>42%</td>
</tr>
<tr>
<td>Medcard</td>
<td>23%</td>
<td>69%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Table 6: Frequency of Response by Tool for the Second Question (Usefulness) of the Tool Preference Measure

<table>
<thead>
<tr>
<th>Tool</th>
<th>Not Useful</th>
<th>Somewhat Useful</th>
<th>Very Useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>e-MedTable</td>
<td>23%</td>
<td>42%</td>
<td>35%</td>
</tr>
<tr>
<td>MedTable</td>
<td>26%</td>
<td>40%</td>
<td>34%</td>
</tr>
<tr>
<td>Medcard</td>
<td>35%</td>
<td>47%</td>
<td>18%</td>
</tr>
</tbody>
</table>

Table 7: Factor Loadings for the Six Items of the NASA-TLX for Simple (left) and Complex (right) Problems

<table>
<thead>
<tr>
<th>NASA-TLX Items</th>
<th>Simple Factor Loading</th>
<th>Complex Factor Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental</td>
<td>.777</td>
<td>.760</td>
</tr>
<tr>
<td>Physical</td>
<td>.760</td>
<td>.635</td>
</tr>
<tr>
<td>Temporal</td>
<td>.885</td>
<td>.818</td>
</tr>
<tr>
<td>Performance</td>
<td>.544</td>
<td>.600</td>
</tr>
<tr>
<td>Effort</td>
<td>.832</td>
<td>.837</td>
</tr>
<tr>
<td>Frustration</td>
<td>.775</td>
<td>.881</td>
</tr>
</tbody>
</table>

Table 8: Mean (and Standard Deviation) Values for the NASA-TLX Compared Between Individuals, the Patients in a Pair, and the Pair Averages

<table>
<thead>
<tr>
<th>Condition</th>
<th>Simple</th>
<th>Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individuals</td>
<td>23.2 (10.2)</td>
<td>36.3 (18.0)</td>
</tr>
<tr>
<td>Patients in Pair</td>
<td>16.2 (9.7)</td>
<td>26.5 (14.5)</td>
</tr>
<tr>
<td>Pair-Averages</td>
<td>16.1 (8.3)</td>
<td>27.0 (12.4)</td>
</tr>
</tbody>
</table>
CHAPTER 5: DISCUSSION

The purpose of this study was to see the impact external tools had on patient/provider collaboration concerning medication planning. Two structured aids (MedTable and e-MedTable) were tested against a less structured tool (Medcard) in a simulated medication scheduling task. The structured aids were predicted to improve accuracy and shorten completion time while also lowering perceived workload because they were structured to reduce the cognitive demands of medication scheduling and facilitate conversational grounding. It was predicted that the MedTable would outperform its computer-based counterpart due to age-related technology preferences and perhaps the cognitive demands of using the tool (e.g., using the mouse to enter medication times). The tools were compared with medication schedule problems that varied in complexity. The more complex problems had more medication constraints and thus a smaller solution space than the simple problems.

The strongest evidence from the experiment showed that the complex problems took longer and were harder to solve (higher workload and less accurate solutions) than the simple problems. This finding may reflect the fact that the complex problems required more constraints to be maintained in working memory while also having fewer solutions which satisfied all of the constraints. Time to search the solution space would be longer for these problems, as reflected in the completion time results. Also, with more effort spent on solving the problems, less effort was spent on optimizing the solutions.

External Artifacts and Performance

Problem solving accuracy was near ceiling for both levels of problem complexity, much higher than the Morrow et al. (2008) study. In that study, medication information had to be added to the tool by the patient. However, in the current study this step was skipped and the medication information started already on all of the tools. Therefore, as soon as any of the tools were given out, the patient and provider instantly had approximately the same knowledge of medications in front of them. This supported more rapid development of common ground around this information compared to verbally exchanging the information. Furthermore, there was no need for the patients to spend cognitive resources to write out the information or
maintain any of it in their working memory. The decision to pre-populate the tools was still a good decision as it eliminated any confounding data that would result from the information having to be written on the paper tools and typed onto the e-MedTable, and is consistent with how the MedTable would likely be implemented in actual health care settings.

**Major findings.** The group using the MedTable created more accurate schedules than the Medcard group. This mirrors the results from the previous study (Morrow et al., 2008). The e-MedTable did as well as both of the paper tools. The difference in accuracy between the MedTable and Medcard accounts for one or two constraints not being met when participants used the Medcard. While there was no tool difference in completion time, the structured tools supported more optimally scheduled solutions, defined as schedules in which medication taking times were minimized and medication doses were spaced appropriately. Groups using structured tools also reported lower workload associated with developing the schedules. Finally, the structured tools were easier to use, which may help explain tool-related differences in workload associated with problem solving.

The structured tools likely affected accuracy, optimality, and workload because structured tools more explicitly represent constraints, which reduces the need to integrate constraints while problem solving. This makes problem solving easier as some cognitive steps are less burdensome or omitted all together. For example, the patient had to keep the daily routine in working memory while considering medication constraints only while using the less structured tool.

Furthermore, the MedTable and e-MedTable presented schedules in a primarily non-textual (visual-graphic) fashion. When the Medcard was used, participants tended to write out the times (hours or events) in a list form. This may have been difficult to synthesize into a full representation of the schedule and therefore cause trouble in holistically organizing the schedule. On the other hand, the structured tools allowed the pairs to see the big picture by way of a mostly visual matrix (Day, 1988). This makes optimizing the schedule easier. Minimizing medication times becomes a process of minimizing columns being used. Dose spacing is transferred into a visual medium; the separation of the x’s is the separation of the doses.
By pre-populating all of the external tools with medication information, the time to achieve shared understanding of medication information may have been eliminated, possibly impacting the problem completion time unevenly for the tools. Also, time was not likely a pressing matter for the participants. In fact, only 15% of the four trial times exceeded ten minutes, which is still five minutes before the limit. Since all participants were told that accuracy was more important, time was only pressing for those who let it influence them. Some groups double-checked their work while others did not, but there was not a consistent way to measure completion time other than waiting for the participants to address the experimenter. Thus, there was a lot of noise in our measurement of solution time, reducing chances of detecting a difference due to the tool.

Unfortunately, the Partner Awareness survey failed to find a lot of substantial evidence that the structured tools influenced the collaborative process. Interestingly, the e-MedTable stood out by itself in regards to quality of collaboration and potentially communication and common grounding.

**Effect of Collaboration**

A secondary aim of this study was to see if collaborative problem solving was more effective than individual problem solving. This was accomplished by comparing the performance of the pairs to the performance of individuals. With regards to the effect of completing these problems with a partner or by oneself, the problems showed some interesting results. For simple problems, there was no significant difference in completion time, but pairs were significantly more accurate than individuals. For complex problems, individuals took less time to complete the problems than the pairs, and although the pairs were more accurate on average, the difference was not significant. For either level of problem complexity, collaboration did not have a significant effect on the creation of optimal schedules. Also, collaboration reduced subjective workload compared to individuals, whether the latter were compared to patients in each pair (the tool user) or to average pair ratings. The former comparison was made since workload could differ depending on the level of interactivity with
the tool; providers had less than the patient. The latter was done to estimate the average perceived workload of the pair and to see if an individual’s experience varied.

Average solution accuracy may have been higher for pairs than individuals because collaboration increased the likelihood of observing problem constraints. For example, one partner can double check the work and give feedback on missed constraints. However, working with a partner can also slow the task down as the pair has to coordinate effort, and there is always a possibility of interference. Errors may be caught and worked out, but time is spent doing so. Interestingly, collaboration did not play a factor in optimality. This might be accounted for since the tools did significantly impact optimality, and tool effects were likely averaged out. The most likely reason that collaboration had an effect on accuracy for the simple problems is that one of the individuals did really poorly on the simple problems, far worse than any of the pairs and thus a great amount of variance was added to the individuals, where the pairs had very little. The trouble with comparing groups of such mismatched size (13 versus 72) is a lot of individual differences are averaged in, possibly causing significant differences to be blurred.

It is understandable collaboration lowered experienced workload even though it increased solution time because pairs could divide up the mental demand and effort required to complete a task. An individual would not have the second person to process information or alleviate some of the pressure that arises from problem solving. As the old adage goes “many hands make light work.” At least in this study, it proved true.

It should be mentioned that the effect of collaboration could have been overestimated in the present study. There is some debate in the field as to how the performance of groups and individuals should be compared. Some researchers think that the most appropriate way to compare group and individual performance is evaluate collaborative performance against “nominal groups”, where individuals are paired and the unique output of each partner combined (for review of this literature, see Meade, Nokes & Morrow, 2009). These groups would allow an estimate of best individual performance to be compared to that of a collaborative group. Unfortunately, there were too few individual participants in the present study to create nominal groups.
The e-MedTable

While we predicted that older adults might be less successful using the e-MedTable than the paper tools, in fact the findings suggested no difference in effects of the two structured tools. While null effects must always be interpreted cautiously, the lack of evidence against the e-MedTable is promising. Even with older adults as the participants, an electronic interface proved to be just as successful as good old paper and pencil. There were very few differences between the e-MedTable and its paper-based predecessor. The e-MedTable did not impair performance or time, and it even reduced workload and was deemed slightly more usable compared to the Medcard. Furthermore, the e-MedTable marginally improved communication and perceived quality of collaboration compared to the Medcard.

Looking at the click data, it becomes clear that the e-MedTable was accessible, easy to learn, clear, efficient, and reliable – several of the characteristics desired in an external artifact (Nemeth et al., 2004); (Wears et al., 2007). Errors with the interface were fairly rare (2.9% of clicks) and easy to recover from (the program did not punish error clicks). Nonetheless, some types of click errors suggested sources of confusion that could be addressed by redesigning the tool. The most prevalent error was clicking upon the scheduling matrix to schedule a medication (occurred 33 times). The other errors related to clicking elsewhere to select medication and clicking on the icons to schedule occurred no more than 8 times each in the trials. To solve the most prevailing error, a future design may include a scheduling matrix in which more direct manipulation could be performed; this would be easier with a touch screen where users could point at the cell in the matrix that corresponded to the time that they wished to schedule a medication. The use of an indirect interface was primarily a limitation of the software, and so a more robust development platform would have to be considered. Furthermore, it may be helpful to input some redundancy within the navigation of the system. Allowing the user to select in multiple locations which medication is being scheduled may allow for quicker use and eliminate the other major errors. However, this should remain limited as too much redundancy could result in the current medication being accidently changed during the scheduling process. Finally, perhaps the icons for key patient events (meals and bedtimes) could be made more salient (larger picture and/or caption), or be removed completely. This
researcher often witnessed many users ignoring these icons and looking onto their patient information sheet to see when meals or bedtimes were. It could be possible that this issue only arose because the patients were not using their actual routine; in a clinical trial there would be no patient information sheet. In these instances, the icons were most likely lost in the interface, and so their effectiveness is yet to be proved.

Implications

Structured tools. The structured tools were successful in lowering the workload experienced by the pairs while improving solution accuracy. This is important in that a task that is easier to accomplish may help motivate users to do the task. The reason for this reduced cognitive demand and effort associated with creating medication plans could be related to the perceived usability of the structured aids. The two measures were inversely related: the lower the workload experienced by the patient, the higher they rated the usability of the tool, $r(72) = -0.26, p < .05$. Considering that the structured tools were designed for the purpose of medication scheduling, whereas the Medcard was meant for keeping track of medication information, it seems evident that the tools would reduce workload related to what they were designed for. Thus, at the very minimum it is a success for the designers. The perceived user-friendliness may help explain the participants’ preferences. The structured tools were seen as more helpful than usual scheduling methods more the Medcard was. Perhaps, a separate tool to provide assistance for planning and scheduling may be better received than a medication reconciliation card.

Whether or not these tools will be well received by providers remains to be seen, but at the very least patients would likely receive these interventions as warmly as the participants did in the present study. Thus it is probably worth the effort to implement an easy to use tool to assist in medication scheduling. After all, if structured tools support more complete and specific communication and collaboration between patient and provider, the increase in the patient’s knowledge could result in more accurate and easier to implement adherence plans. This would likely improve adherence, which in turn would improve health outcomes and reduce costs.
An electronic structured tool. Research involving computers and collaboration rarely involves a co-located collaborative medium, especially where multiple users share only one screen and one input device. Although in this study there were minimal issues with one person controlling input, should an e-MedTable be implemented serious consideration should be given to determine who would have control or whether two input devices should be allowed, giving the provider top-level control (similar to cars used in driver’s education). The e-MedTable stands to be a step in the right direction towards remedying the fact that there currently exists no collaborative aid for medication scheduling in a typical healthcare center. With the rise of interest in healthcare information technology, the e-MedTable could be the predecessor to a viable electronic tool that could improve patient-provider communication about medication. A program like the e-MedTable could be implemented into a electronic medical record where not only would it be populated by the medications in the patient’s file, but also be kept with the file for easy updates as medications change.

Limitations

There are several limitations of this study. The first limitation is common to many simulation studies. Although the participants were divided into the roles of patient and provider, the collaboration of a real patient and provider would probably look much different. To begin with, the provider in the simulation was not a true expert in medication or general health practices. The impact on collaboration of the knowledge a real provider would bring to medication planning could only be guessed. The participant providers also varied in the level of interactivity and communication they had with the patient. Even though the provider was told to lead the discussion, a number of different interactions happened. If the provider was more reserved, they often said little or let the patient lead since the patient had ultimate control over the schedule. Sometimes the provider would even be ignored in the conversation, which seems atypical of traditional provider-patient interactions. On the other hand, some providers dictated and controlled the conversation completely; this might be the way some real providers would use the tool, which is why the true interactivity of the tool in an actual clinical setting needs to
be studied. Patient-provider communication is not well structured and likely varies as much as it did in this study; the effect of the tools with a real provider is yet to be seen.

This study also did not truly measure the impact the tools had on the collaborative process. Outcomes were measured, but to understand the complexities of how collaboration was transformed by an external representation would require in-depth analysis of the audio transcripts. The effect the tools had on grounding or what were the most successful strategies can only be conjectured. Although the three tools immediately provided content common ground (medication information), there is no clear measure of how to capture process grounding (Convertino et al., 2008), the mental models each person associates with doing a scheduling task. Were the pairs coming to an agreement on how they viewed the problems themselves? The closest way to get the answer was through the questions from the Partner Awareness Survey.

Similarly, another issue that arises in a simulated study is the lack of realism. The study probably did not capture how the patients interact with their actual provider. Although there may have been SES differences between partners, they were likely much smaller than those experienced in real clinical communication; any roadblocks arising from SES differences were not addressed in this study. Furthermore, the participants were highly educated and familiar with computers; health literacy was not measured, but most of the participants probably had good functional health literacy. The applicability of these findings on lower educated, less familiar with computers, or lower health literacy patients cannot be determined in the present study.

Realism also affects the medication problems themselves. Although the problems were made as realistic as possible, often providers do not stress the importance of taking medications at an exact time. However, the lack of firm schedules in many people’s daily life can likely contribute to nonadherence. Many times, regimens can be simplified to taking pills only a couple of times a day. However, there are regimens that do have strict time schedules, such as anticoagulants or HIV-related medications, and the literature suggests patients have trouble following these regimens.
Another limitation is the generalizability of this study to actual clinical settings. The time for solving the problems may have been too long as it may be too unrealistic to think that providers would be willing to spend 15 minutes to schedule medications. It might not be feasible to use the tool in every visit with every patient that is prescribed medication. The tool might only be used with chronically ill patients taking a lot of medications. However, medication reconciliation is heavily stressed as being important for all patients (Apsden et al., 2007), and an interactive reconciliation tool may still be generally helpful.

Finally, the last notable limitation of this study is in the electronic tool itself. The tool was developed for six static problems. It was not built to be malleable and adaptable to different combinations of medications and patient routines. A future tool would have to be customized for an individual’s daily schedule and medications. The tailoring process would also have to be developed to be efficient and accessible. Integration with an EMR might facilitate this process.
CHAPTER 6: CONCLUSIONS

Medication adherence is a serious issue in the United States. Adhering to a medication plan is not trivial. It often requires creating and implementing plans for taking multiple medications, which can burden cognitive abilities, such as speed of processing, working memory, and recall. This problem is exacerbated for older adults who experience age-related cognitive decline of these abilities. Fortunately, adherence can be promoted through effective communication and collaboration with healthcare professionals. However, the current quality of provider-based support for medication scheduling is inadequate.

This study looks at the possibility of using external tools to support collaboration and problem solving in an adherence task. Three external tools – two structured for the task and one less structured but commonly used in actual health settings – were tested to see their effect on collaborative medication scheduling. I found that a structured tool improves the problem solving accuracy of a pair more so than a pair using a less structured tool. Structured tools decreased the subjective workload experienced by its users more so than a less structured tool. The structured tools were also rated as more usable, helpful, and useful than the less structured tool. Finally, there is limited evidence that a structured tool supported perceived quality of communication and grounding more than a less structured tool. Thus, a structured tool provides for a more desirable experience for the user when completing a medication scheduling task.

Collaboration in a pair also improved problem solving accuracy in medication scheduling problems more than individuals. Also, compared to an individual, collaboration lowered the subjective workload experienced by the participants. Future research can address whether the external tools (structured or less structured) especially support collaborative (compared to individual) problem solving.

Finally, an electronic interface demonstrated to be as successful as a paper based tool in regards to medication scheduling. All of the participants were over sixty, and yet they did not have any more trouble using the computer tool than the paper-based tools. Thus, an electronic tool can prove to be a viable option for collaboration and communication between older adults.
and their providers. A tool such as this could simultaneously solve two of the major recommendations from a 2007 IOM study (Apsden et al., 2007):
1. Patients should maintain an active list of medications for all providers.
2. All healthcare organizations should make available decision-support tools for prescribing medication.

Future Directions

A version of the e-MedTable should be tested within the context of an actual healthcare setting. This will determine the impact such a tool could have on communication between real providers and patients, and show if medication adherence would be improved through such an intervention. Future iterations could also take advantage of the ever advancing field of ubiquitous computing; similar software programs could be developed for handheld/portable devices and may even be added to personal health record systems. At the very least, the e-MedTable could be able to create hard copy schedules to be sent home with the patient. Hopefully, employing such a tool and also stressing implementation intentions will result in improving medication adherence in all age levels.
REFERENCES


APPENDIX A: THE MEDICATION SCHEDULING PROBLEMS

The medication problems that were the main method for gathering data on problem solving are found in a supplemental file named Medication_Problems.pdf.
APPENDIX B: THE PARTNER AWARENESS SURVEY

The Partner Awareness Survey given to the participants to collect data on collaboration that was presented in this thesis may be found in a supplemental file named Partner_Awareness.pdf.
APPENDIX C: THE TOOL USABILITY SURVEY

The Tool Usability Survey given to the participants to collect data on the usability of the three tools may be found in a supplemental file named Tool_Usability.pdf.