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THE INTERACTION BETWEEN INTERNAL AND EXTERNAL INFORMATION ON RELATIONAL DATA SEARCH

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THE INTERACTION BETWEEN INTERNAL AND EXTERNAL INFORMATION ON RELATIONAL DATA SEARCH

A

DISSERTATION

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DEDICATION

To my father and mother

with thanks for a lifetime of love and support

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I have experienced a rich and rewarding academic life at the University of Texas Health Science Center at Houston while studying and working at the School of Health Information Sciences. Consequently, I want to acknowledge my gratitude to those individuals who have played significant roles in my training for an academic/professional career.

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ABSTRACT

People often use tools to search for information. In order to improve the quality of an information search, it is important to understand how internal information, which is stored in user's mind, and external information, represented by the interface of tools interact with each other. How information is distributed between internal and external representations significantly affects information search performance. However, few studies have examined the relationship between types of interface and types of search task in the context of information search.

For a distributed information search task, how data are distributed, represented, and formatted significantly affects the user search performance in terms of response time and accuracy. Guided by *UFuRT (*User, Function, Representation, Task), a human-centered process, I propose a search model, task taxonomy. The model defines its relationship with other existing information models. The taxonomy clarifies the legitimate operations for each type of search task of relation data. Based on the model and taxonomy, I have also developed prototypes of interface for the search tasks of relational data. These prototypes were used for experiments.

The experiments described in this study are of a within-subject design with a sample of 24 participants recruited from the graduate schools located in the Texas Medical Center. Participants performed one-dimensional nominal search tasks over nominal, ordinal, and ratio displays, and searched one-dimensional nominal, ordinal, interval, and ratio tasks over table and graph displays. Participants also performed the same task and display combination for two-dimensional searches.

Distributed cognition theory has been adopted as a theoretical framework for analyzing and predicting the search performance of relational data. It has been shown that the representation dimensions and data scales, as well as the search task types, are main factors in determining search efficiency and effectiveness. In particular, the more external representations used, the better search task performance, and the results suggest the ideal search performance occurs when the question type and corresponding data scale representation match. The implications of the study lie in contributing to the effective design of search interface for relational data, especially laboratory results, which are often used in healthcare activities.

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VITA, PUBLICATIONS AND FIELD OF STUDY

2006	Ph.D. Health Informatics	University of Texas Health Science Center at Houston
1997	M.S. Medical Informatics	Peking Union Medical College
1992	M.D.	China Medical University

PUBLICATIONS DURING STUDY

1. Gong Y. Zhang J. A human-centered design and evaluation framework for information search. American Medical Informatics Association 2005 Annual Conference Doctoral Consortium, Oct. 2005.

2. Gong Y. Zhang J. Distributed information analyses for information search tasks. Proceedings / AMIA. Annual Symposium 2005: 281-5

3. Thronesbery C, Malin J, Jenks K, Overland D, Oliver P, Zhang J, Gong Y, Zhang T. A data-based console logger for future mission operations team coordination. In: Proceedings of IEEE Aerospace Conference 2005. Washington, D.C.; 2005.

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6. Michea YF, Pancheri K, Gong Y, Bernstam E. Comparing communication technology on Chinese, English, and Spanish diabetes web sites. Proceedings / AMIA. Annual Symposium 2002:523-7.

FIELD OF STUDY

Clinical Informatics; Health Informatics; Human-Computer Interaction

INTRODUCTION

Searching for information in an information-rich setting often involves many steps and requires tools (Dervin, 1999; Eisenberg & Berkowitz, 1990; Fidel & Bruce, 2000; Gaslikova, 1999; Lancaster & Warner, 1993; Marchionini, 1992). How the information is distributed across internal representations (stored in the user's mind) and external representations (presented on information tools) affects the efficiency of the information search (Zhang, 1996).

WHY STUDY SEARCH TASKS FOR RELATIONAL DATA

Healthcare professionals in their daily practice are exposed to vast amounts of laboratory data. Such exhaustive displays can easily overwhelm their ability to understand the data, reduce their ability to detect trends, and therefore, prolong the decision-making process. Relational data, specifically laboratory data, plays an important role in patients' records and its effective representation should be taken into account in patient record systems (Denekamp *et al.*, 2005).

In order to improve the quality of an information search on relational data, it is important to understand how internal and external information interact with each other. A typical task in an Electronic Health Record (EHR) system could be, for example, to find all the abnormal values of the lipid panels of a patient over the past 12 months. In this task, the normal range required, if not presented on screen, is internal information. The observed values, which are presented in the patient's record, are referred to as external information. How the information is distributed between internal and external representation affects the information search performance. However, few studies have examined the relationship between types of representations and types of search tasks (Komlodi, 2004). For the lipid panels in a patient's record, the observed values, for example, can be presented in the format of a table, a graph, or in a mixed display of a table and a graph. There appears to have been no research conducted relative to which kind of representation is the most effective for different tasks.

The research motivation here primarily arises from the interfaces currently presented in some EHR and used by clinicians to make healthcare decisions. The healthcare domain has a time-critical, life-relevant, and multi-tasking nature. Undoubtedly, effective searches on healthcare data facilitate the decision-making process and potentially improve healthcare quality. Relational data, as important components of a patient's record, play an indispensable role in healthcare delivery. However, little has been done to scientifically explore effective methods for representing the relational data.

THEORETICAL BACKGROUND

While information search efficiency can be improved by several factors that characterize human information behaviors, such as choice of information sources, searching strategies, methods of verification of information reliability and correspondence with earlier data (Gaslikova, 1999), my focus is on cognitive factors and their implications on human-computer interaction. This is because distributed cognition provides an effective theoretical foundation for understanding the human-computer interaction and it provides a useful framework for designing and evaluating information-searching tools (Hutchins, 1995; Norman, 1993).

Distributed cognition is a branch of cognitive science that proposes which elements of human knowledge and cognition are not confined to individuals, but rather distributed across time, space, people and artifacts. Distributed cognition analysis is a useful approach for designing an information system. The theory of distributed cognition (Hutchins, 1995, 2000; Hutchins & Klausen, 1996; Zhang & Patel, (in press)), puts emphasis on individuals and their environment and it views a system as a set of representations. These representations can be either internally stored in the user's mind or externally represented by the artifacts.

Zhang (Zhang, 1991) proposed the theory that external representations are not simply peripheral aids but an indispensable part of cognition. According to Zhang's theory, external information presented in an appropriate format can reduce the difficulty of a task by supporting recognition-based memory or perceptual judgments rather than recall.

In addition to the distributing pattern that explains the internal and external requirements, the format of information (e.g., nominal, ordinal, interval, ratio) also affects user performance when searching for information (Zhang, 1991). Currently, there is a lack of theoretical understanding of how performance is affected by information display in terms of data scale in an information-distributed setting. Therefore, a systematic approach that describes, explains, and predicts the search performance for relational data is needed.

Relational Information Display (RID) is another approach that emphasizes the relationship between represented dimensions and representing dimensions (Zhang, 1996). These two dimensions have to be matched in scales so as to guarantee efficient and accurate representations between the display and the world.

GOALS OF STUDY

The purpose of this study is to understand how internal and external information jointly determines relational data search efficiency in terms of response time and correctness. A task taxonomy for relational data search serves as a guideline to develop search tasks for empirical studies and user interfaces, which represent data in different data scales. In particular, the study employs experimental methods to examine the relationship between internal and external information, search question types and interfaces, and to discover error rate and response time.

The fundamental principles of this research will facilitate and support the design and evaluation of human-centered information systems.

ORGANIZATION OF DISSERTATION

The dissertation is organized as follows. Chapter I provides the theoretical basis for developing a framework of distributed information search. Chapter II describes the theoretical framework of the research design and methods used for collecting data. Chapter III provides a detailed description of theoretical analysis, consisting of experimental materials and procedures employed. Chapter IV depicts experimental designs and the procedure for acquiring data. Chapter V contains a summary of the data collected, the statistical methods employed to analyze the data, and the major results obtained. Chapter VI is intended to be a discussion section which includes significant findings from Chapter III and their implications. Finally, Chapter VII offers concluding comments, including an acknowledgement of the limitations of the study as well as suggestions for future research.

CHAPTER I

THEORETICAL FOUNDATION

This chapter reviews the pertinent literature on distributed cognition, information search, representation effects, scales and information presentation. It provides the basic concepts for developing a theoretical framework for distributed information search.

DISTRIBUTED COGNITION

Distributed cognition plays a special role in understanding the interactions between people and technologies (Hollan *et al.*, 2000). According to the theory of distributed cognition, cognitive activities are distributed across human minds (internal), external cognitive artifacts (external), groups of people, and across space and time (Hutchins, 1995; Norman, 1993; Zhang & Patel, (in press)). Unlike traditional theories, it extends cognitive processes beyond individuals to encompass interactions among groups of people and with resources and materials in the environment. Norman (Norman, 1993) argued that knowledge may be as much in the world as it is in the head. He further pointed out that the information carried by artifacts was as important to the achievement of a task as the knowledge residing in the mind of the artifact user.

Applying the theory of distributed cognition to information search, cognitive processes may involve coordination between internal and external (material or environmental) structures. When searching for information using computers, the information displayed by the user interface and the information in the user's memory jointly determines the performance level of the search task.

DISTRIBUTED INFORMATION SEARCH

Information search efficiency can be improved by several factors that characterize human information behaviors, such as the choice of information sources, searching strategies, methods of verification of information reliability, and correspondence with earlier data (Gaslikova, 1999). My focus is on cognitive factors and their implications on human-computer interaction. This is because distributed cognition provides an effective theoretical foundation for understanding human-computer interaction and is a useful framework for designing and evaluating information-searching tools (Hutchins, 1995; Norman, 1993).

Studies of factors that affect human needs and information search behavior have usually focused on the process of query formulation, execution, and results evaluation (Bystrom & Jarvelin; Eisenberg & Berkowitz, 1990; Grudin, 1990; Hayden; Marchionini, 1992; Zeng & Cimino, 2000). Existing information search models define a search task from the need of information seekers as well as from the evaluation of results (Bystrom & Jarvelin, 1995; Marchionini, 1992; Schneiderman, 1998). Information Foraging Theory (Pirolli & Card, 1999) is an approach to understanding how strategies and technologies for information seeking, gathering, and consumption are adapted to the flux of information in the environment. It focuses on the allocation of attention and assumes that people, when possible, will modify their strategies or the structure of the environment to maximize their rate of gain valuable information. Figure 1 presents the relationship of such information models.

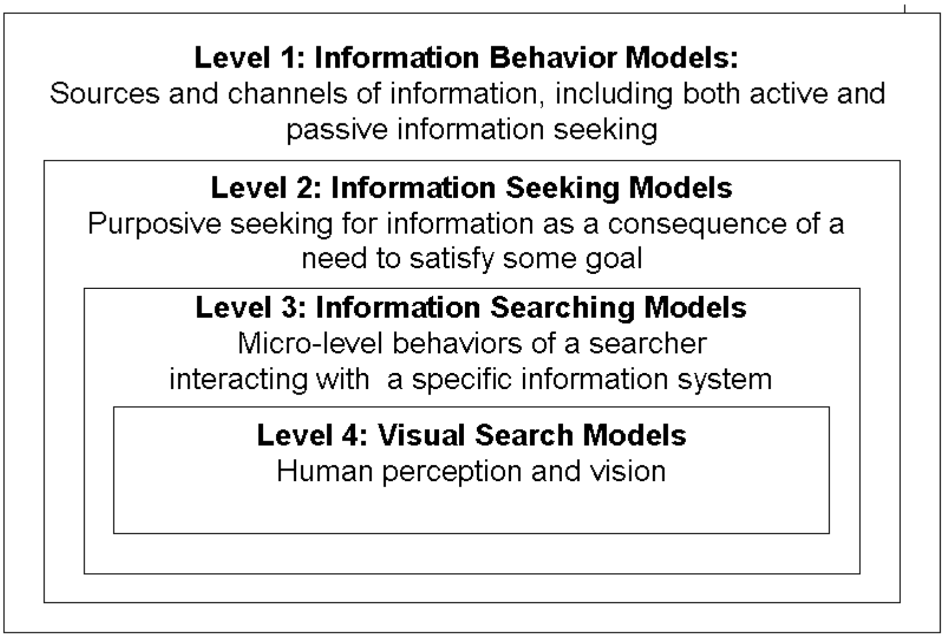


Figure 1. Existing information models

Information models at Level One place emphasis on human behavior in relation to sources and channels of information. Information behavior includes both active and passive information seeking and use. Therefore, this contains face-to-face communication with others, and the passive reception of information as in, for example, watching TV advertisements, without any intention to act on the information given. Wilson's model is a representative model in this category. It focuses on causes, consequences and relationships among stages of an information-search activity (Niedzwiedzka, 2003). Allen's gatekeeper model (Allen, 1977) refers to "a small number of key people to whom others frequently turned for information. These key people differed from their colleagues in the degree to which they exposed themselves to sources of technological information outside their organization". Information models at Level One generally define the totality of human information behavior. However, they are of little practical use in designing information systems which typically require strong interactions between human and the technologies.

Information models at Level Two particularly concerned with the variety of methods people use to discover and gain access to information resources. Representative models at this level include Dervin's sense-making theory (Dervin, 1983), and Ellis's behavioral strategies (Ellis, 1989; Ellis *et al.*, 1993). At this level, information seeking is considered as a purposive seeking to satisfy the need to achieve a goal. In the course of seeking, the individual may interact with manual information systems, for example, a newspaper or a library, or with computer-based systems. However, models at this level have little value in analyzing and predicting search performance because they do not define the complexity of the searching process.

Information models at Level Three are a subset of seeking behavior employed in interacting with information systems of all kinds. Luhlthau's model (C. Kuhlthau, 1991; C. Kuhlthau, 1993) suggests that the user of an information system is an active participant in the information search process. More importantly, Luhlthau pointed out that cognitive processes are involved in information seeking. Memory plays a critical function in the process of using information. With users' limited capacity for recall, users remember selectively rather than recalling everything. Recall is based on former constructs that form a frame of reference for selective remembering. Saracevic (Saracevic, 1996) examined traditional and interactive models that have emerged in information retrieval, and proposes an interactive model based on different levels in the interactive processes. Luhlthau and Saracevic’s models particularly concerned with the interactions between user and computer-based information systems. They are suitable for describing the interactions but they lack of effective methods for analyzing and predicting the complexity and performance. Analyzing and predicting the search performance of users is highly important in designing a human-centered information retrieval system. My current study on distributed information search falls into this category.

Information models at Level Four are visual search models which are particularly about the cognitive strategies that people use on specific displays. People perform visual search in parallel, sequential, and/or mixed search methods. Among these models, the theory of the proximity compatibility principle predicts that integral displays are suited for integrative tasks while separable displays facilitate focus tasks (Wickens & Carswell, 1995). An integral display combines several dimensions in a single object whereas separable displays show data of different dimensions in different planes. The models at this level are of help in explaining the information search performance in terms of the patterns of information distributions.

All the models are either too broad or too narrow when they are applying to a domain with information overload, time pressure, and stress, they cannot adequately address the distributive, interactive nature of an information search. For models designed for complex domains and in which users and their tasks have a multifarious and rich nature, distributed information resources should be considered (Zeng & Cimino, 2000). In healthcare, due to the time-critical nature, patient's data is often presented in a non-flexible way lacking of alternatives. When healthcare professionals need to make decisions under time pressure and stress, providing an efficient and effective representation appears to be time-saving, rather than providing the choice of data representations to the healthcare professionals. My study focuses on a theoretical framework and task taxonomy which describe, explain and predict the search performance.

REPRESENTATIONAL EFFECTS

Zhang proposed the theory that external representations are not simply peripheral aids but are indispensable parts of cognition (Zhang, 1991). According to Zhang's theory, different isomorphic representations of a common abstract structure can generate dramatically different representational efficiencies, task complexities, and behavioral outcomes (Zhang & Norman, 1994). This representational effect, referred to as external information presented in an appropriate format, can reduce the difficulty of a task by supporting recognition-based memory or perceptual judgments rather than by simply relying on recall. In many tasks, such as those in my study, people often use external artifacts to enhance internal memory and the artifacts are often created specifically for the purpose of aiding the memory. For example, a patient chart is designed for reviewing the patient's medical history. Proper external representations support internal memories and therefore enhance task performance.

Relational Information Displays (RIDs) are those that represent the relationship between dimensions (Zhang, 1996). The represented dimensions of a RID refer to the dimensions of an original domain in the world represented by various RIDs. The representing dimensions refer to the physical dimensions of RIDs representing the dimensions of the original domain in the world. These two dimensions have to be matched in scale so as to guarantee the efficient and accurate representation between the display and the world (Zhang, 1996).

PROXIMITY COMPATIBILITY PRINCIPLE

In the field of scientific visualization, proximity compatibility principle predicts (Wickens & Carswell, 1995) that integral displays are suited for integrative tasks while separable displays facilitate focus tasks. An integral display combines several dimensions in a single object whereas separable displays show data of different dimensions in different panels. Wickens and his colleagues conducted a series of studies concerning the appropriateness of graphical display, task type, and the integration of dimensions.

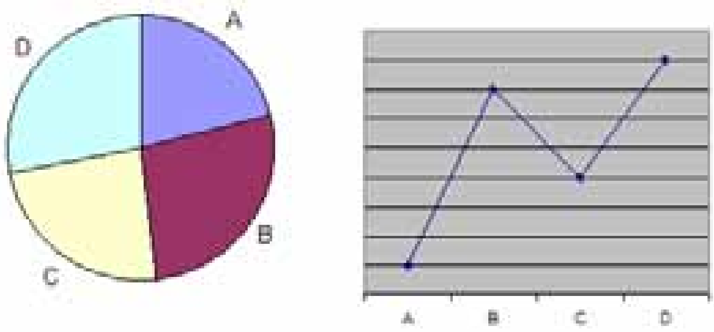
The "proximity compatibility principles" describes that an optimal display should be both physically and perceptually proximate and compatible. Proximity is defined in terms of sharing of features between displayed attributes such as closeness in space, identity in color or similarity of semantic meaning. However, this principle has its limitations to non-graphical representations and graphical representation with different formats of data scales. Besides the physical and perceptual proximity and compatibility, an optimal display must conform to the task requirements. If the requirements are not met, a search task can not be performed. For example, water depths represented by ordinal data scale, i.e. low, ok, high can not answer the question, "how many feet is the water higher/lower than sea level".

Moreover, when in a situation that both internal and external information are required to perform a search task, the perceptual compatibility does not adequately reflect the representational effect. The represented and representing dimensions must be both considered and should match tasks so as to guarantee the efficient and accurate representation among the display, the world and the task.

TASK TAXONOMY

According to the proximity compatibility principle, the merits of separable and integral displays are dependent on the task nature, which is either a focus task or an integrative task. This task taxonomy classifies the task types in terms of the degree of information integration. Specific examples of tasks that fall into point-reading, local comparisons, global comparisons, or synthesis (Carswell, 1992) are given in Figure 2. In general, these task categories vary from one involving focal attention to a single point-reading to those involving integration of most or all of the graphed values. This taxonomy is helpful in understanding task nature when represented in graphs. However, the legitimate operations based on data scales are not considered in this taxonomy.

In practice, graphical presentations are rarely useful in pure focus tasks and medium integration tasks such as reporting single values. Several researchers pointed out that graphs should be used to convey an overall pattern while tables are better for looking up data points (Kosslyn, 1994; Ware & Beatty, 1986; Yu & Behrens, 1995).



Point Reading:	What is the value of pie slice B? Point D?
Local Comparisons:	Is D grater than C?
	How much greater is D compared to C?
Global Comparisons:	Is A+B equal to C+D?
	Is D greater than the average of A and C?
Synthesis:	Is the variability of the data points large?
	What is the value of data point E (extrapolation)?

Figure 2. Examples of the four task classifications used in coding the Carswell's studies with reference to a sample line graph and pie chart (reproduced from Carswell, 1992)

SCALES AND INFORMATION PRESENTATION

In a RID, the dimensions are basic units designed to describe the relationships within the data. On a finer granularity of dimensions, the scale type of data provides the details on how data are interrelated. The notion of scales is important for understanding the complexity and operability of information searching tasks (Petersen & May, 2006). Stevens proposed a distinction among four types of scales: nominal, ordinal, interval, and ratio(Stevens, 1946). The scale type of the data determines which operations can be legitimately applied to them. The four scales each have different strengths in operations. Ratio is the most powerful scale. It allows the entire set of operations. Operations 1 to 4, described below, are accumulative, which means the bigger number of operations may also include those operations in smaller numbers:

1. Determination of equality of two instances on the scale (=) (nominal scale);
2. Determination of the rank-order (greater or less) of two instances on the scale (>,<) (ordinal scale);
3. Determination of equality of differences on the scale (+,-) (interval scale); and
4. Determination of equality of ratios on the scale (/,*) (ratio).

For example, interval scale, besides its determination of equality of differences, may allow all the operations that either the nominal or ordinal scale allows. Applying the notion of data scale to information searching tasks, each type of search task is expanded as a set of operations which can be legitimately applied to data on different scale types. Accordingly, a set of search tasks based the health data of a patient have been developed for each scale type. Selectively examining the clinically meaningful tasks in different representation formats may help explain the reason why some tasks are more difficult in certain representations than those in seemingly isomorphic representations[1].

THEORETICAL FRAMEWORK OF HUMAN-CENTERED DESIGN

Built upon the theory of distributed cognition and a set of analysis techniques, Zhang *et al.* developed a method called User, Function, Representation, Task *(UFuRT*) for the effective design and evaluation of human-centered distributed information systems (Gong & Zhang, 2005; Zhang, 2006; Zhang *et al.*, 2002). This method emphasizes functions, users, tasks, and representations as indispensable components of a human-centered information system design. It provides systematic principles, guidelines, and procedures for designing human-centered information systems. In addition, *UFuRT* can predict performance levels of different tasks on different interfaces. Theoretically, an information search interface designed by the *UFuRT* process ensures that the design matches the information search task, thus leading to better task performance.

User Analysis is the process of identifying characteristics of users, such as their expertise and skills, knowledge, age, education, cognitive capacities and limitations, perceptual variations, etc. It provides user information for the functional, representational, and task analyses, therefore helping to design

[1] According to the definition of Wikipedia, if there exists an isomorphism between two structures, I call the two structures isomorphic. Isomorphic structures are "the same" at some level of abstraction; ignoring the specific identities of the elements in the underlying sets, and focusing just on the structures themselves, the two structures are identical.

information systems with the knowledge and structure which will match those of the users.

Functional Analysis is the process of identifying top-level domain structure and ideal task space, independent of implementation. It provides dimensions, relations among the dimensions, operations involving the dimensions, and relations which involve more abstract information than task and representational analyses.

Representational Analysis refers to identifying an appropriate information display format for a given task performed by a specific type of users. In this way, the interaction between users and systems is effective.

Task Analysis is the process used to identify the procedures and actions to be carried out in order for information reach a goal. For each step in a task, the information needed to carry out that step can be either internal or external. The steps and the information needed for each step in the task determine the efficiency, task difficulty, and the possibility of making errors.

User Analysis provides information for the Functional, Representational, and Task analyses. Functional Analysis explains the constraints and limitations of Representational and Task Analyses. Representational Analysis identifies dimensions and scales for displays. Ultimately, Task Analysis presents the detailed requirements necessary to fulfill a task which can be used to scientifically compare the efficiency and to predict user performance. Figure 3 illustrates the relationship between each analysis in the *UFuRT* process.

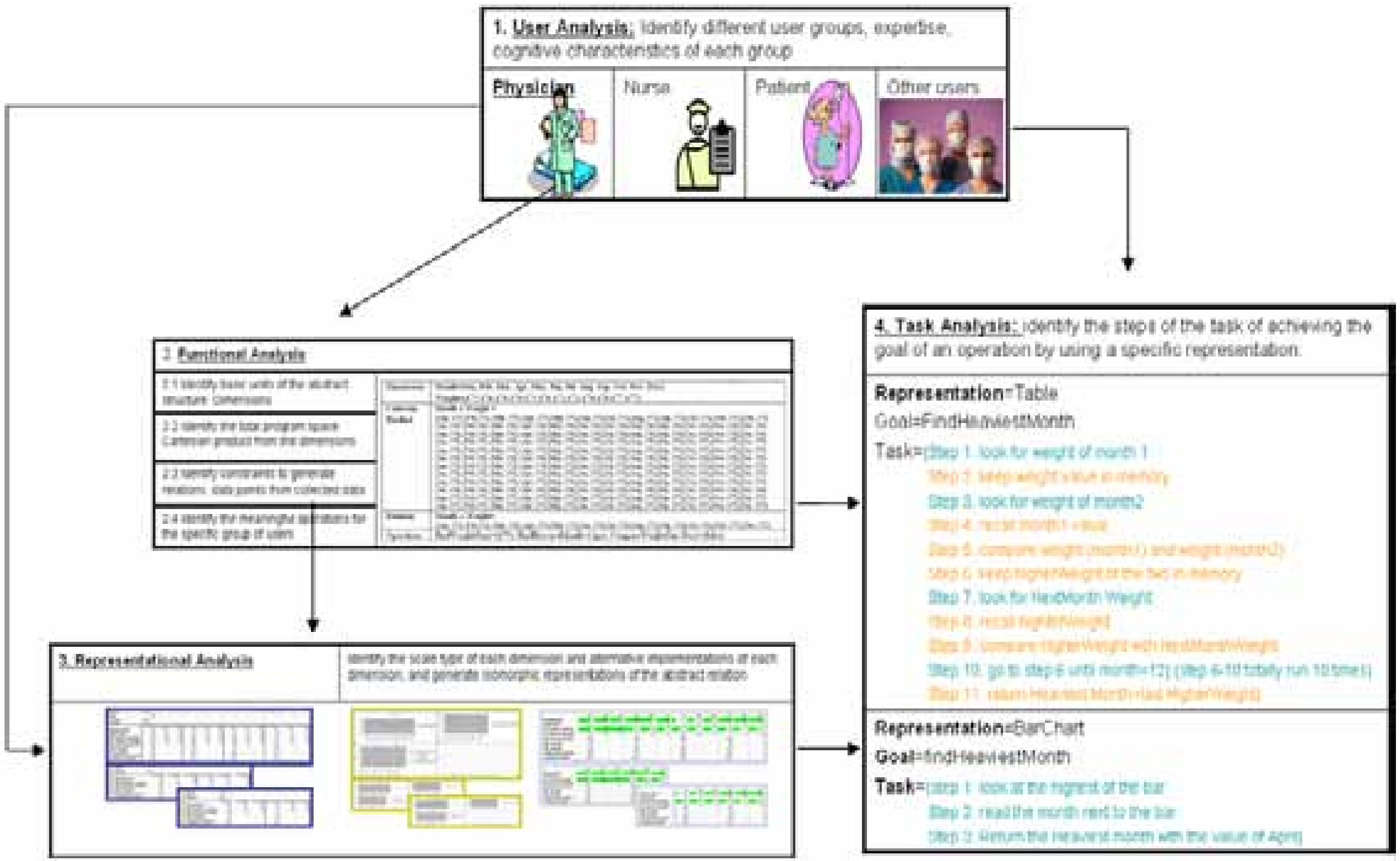


Figure 3. An overview of user, function, representation, and task analysis for design and evaluation of a health information system, i.e., an example of the *UFuRT* process (based on Zhang, *et al.*, 2006)

In addition to the *UFuRT* process which establishes the mapping of users, functions, representations, and tasks in an information system, Goal-Operator-Method-Selection (GOMS) is a useful tool for conducting task analyses in order to reveal information distributions for search tasks. GOMS analysis is a widely accepted method for analyzing human-computer interaction (John & Kieras, 1996). Combining GOMS with distributed cognition analysis provides us a unique perspective on the internal and external information required in each step of an information search. I believe that the internal and external information required for each step can be used to predict the efficacy of specific search tasks.

SUMMARY

This review of the pertinent literature shows the theoretical foundation for distributed information search studies. Distributed cognition helps explain the interaction between humans and technologies. Representation effects reveal that there is no universal method to effectively represent the external information. However, in order to guarantee efficient and accurate representations between the display and the world, the represented and representing dimensions have to match each other. At a finer level of granularity, the data scales for each dimension should also match, so as to guarantee the successful completion of search tasks.

CHAPTER II

A TAXONOMY OF SEARCH TASKS AND A DISTRIBUTED INFORMATION SEARCH TASK MODEL

This chapter presents the application of *UFuRT* for developing a taxonomy for distributed information search. Based on the literature review on existing information models and their theoretical frameworks, I propose a taxonomy of search tasks and a distributed information search task model.

A TAXONOMY OF SEARCH TASKS

When applying *UFuRT* to search tasks in healthcare, a full consideration of users and their duties is critical to an effective information system design and affects healthcare quality in the long run. For a type of clinical trial data, certain types of display are superior to other isomorphic representations in terms of search performance (Elting *et al.*, 1999). A variety of studies have shown that users, such as clinicians and medical researchers, may view the same data set in different ways (Aendonca *et al.*, 2001; Gorman, 1995, 2003; Hersh & Hickman, 1998; Mendonca *et al.*, 2001; Petersen & May, 2006; Song & Soukoreff, 1994; Wilson, 2004). For example, a clinician group may include, but not be limited to, physicians, nurses, dieticians, pharmacists. A clinical research group might include, but not be limited to, epidemiologists and clinical statisticians. All these individuals may have common questions when attempting to solve a certain problem or make a decision relative to diagnosis and treatment, or they may need to check the background information of diseases (etiology) or they may need to keep up with the latest information of or a given subject, in order to keep abreast of the professional development and to continue their medical education. However, when examining the same collection of medical records, they may use different approaches to conduct their research. Clinicians' interests are typically about various aspects of a particular patient at an individual level, whereas a clinical statistician may view the patient records at a collective level, hoping to reveal the trend or epidemic status of a disease.

A patient record contains both free text descriptions, often read in the reports or discharge summaries, and relational data, which exists typically in the lab results section. I believe they are the basic two types of descriptive information, and all other types, such as x-ray reports and graphs can be converted into these two categories for information search purposes.

In this study, I investigated an example of relational data drawn from lipid panel lab results. I used these results to conduct my empirical studies on the effect of interaction between the type of information displays and the relational data search tasks. Figure 4 illustrates the model I used in this study.

Information search efficiency can be improved by several factors that characterize human information behaviors (Hutchins, 1995; Norman, 1993). The focus of this research is on cognitive factors and their implications on human-computer interactions. My model is particularly concerned with the interactions between user and computer-based information systems. My model is a subset of information behavior models and information seeking models (Allen, 1977; Bystrom & Jarvelin, 1995; Dervin, 1983, 1999; Ellis, 1989; Ellis et al., 1993). My model also has a close connection with visual search models which depict cognitive strategies that people use on specific displays. People perform visual searches in parallel, sequential, and/or mixed search methods. These models at the visual search level could be of help in explaining the information search performance in terms of the patterns of information distributions (Hornof, 2004; Hutchins & Klausen, 1996).

DISTRIBUTED INFORMATION SEARCH TASK MODEL

The information search model I propose here is from the resource perspective. Choosing proper information search resources is vital in time-critical, complex information systems, because using the proper resources or tools can provide the required information in a more timely manner as a result of the interaction between internal and external information.

In a healthcare setting, certain types of display are superior to other isomorphic representations in terms of search performance (Elting et al., 1999). A variety of studies have identified that users such as clinicians and medical researchers may use the same data set in different ways (Aendonca et al., 2001; Gorman, 1995, 2003; Hersh & Hickman, 1998; Mendonca et al., 2001; Petersen & May, 2006; Song & Soukoreff, 1994; Wilson, 2004). For example, a clinician group perhaps includes but not be limited to physicians, nurses, dieticians, pharmacists. A clinical researcher group may include but not be limited to epidemiologists and clinical statisticians. These two groups may have common questions in order to solve a certain problem or make a decision regarding diagnosis and treatment, or they may need to check the background information of diseases (etiology) or they might want to be kept abreast of the latest information on a given subject, to remain current in their professional development and/or to continue their medical education. However, examining the same medical records, they may use different approaches as they conduct their research. Physicians' interests are typically about various aspects of a particular patient at an individual level, whereas clinical statisticians may view the patient records at a collective level to reveal the trends or epidemic status of diseases.

A patient record contains both free text description within the medical notes, and the relational data, usually found in the lab results section. I believe they are the basic two types, and that all other types, such as x-ray reports, graphs and other results can be converted into these two categories for information search purpose. In this study, I investigated an example of relational data drawn from the lipid panel lab results. I used these results to conduct my empirical studies on the effect of type of relational information displays and tested the relational data search tasks. Figure 4 illustrates the model I followed in this study.

Different types of information search tasks may require different internal and/or external information depending on the nature of the device and the task. My model indicates that the source selection is dependent on the pattern of information distribution during the execution stage in an information search task. My model is not developed to replace any existing models of information search.

Rather it adds the distributed information aspect to these models and fits well into them.

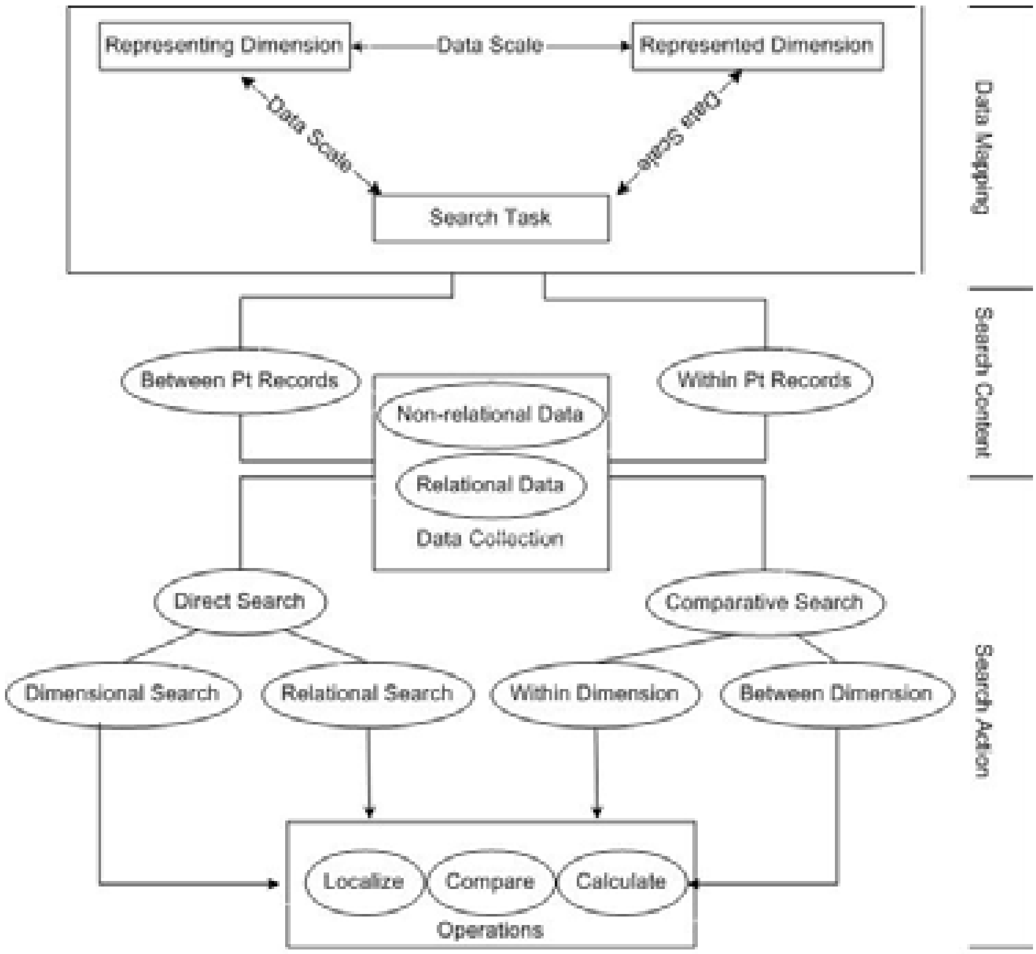


Figure 4. Human-centered information search model

According to the functional analysis, a record of a patient constitutes many aspects of the represented information. An information searching task is a process to search for specific information in the relations/dimensions. Further, search tasks can be categorized into direct searches and comparative searches. A direct search is to find a specific value under specific conditions. Direct search tasks could further be divided into dimensional searches and relational searches. A comparative search compares the value within one dimension (within-dimension search) or between two or more dimensions (between-dimension search).

Localization, Comparison and Calculation

This section describes the search task taxonomy for relational data. A searching task of relational data involves localization, comparison, or calculation.

- *Localization* is a cognitive process to find specific information in a relational information display. In other words, it is a process to identify the target data through base data. In this process only external information is involved.
- *Comparison* is a cognitive process to identify whether the target data is equal to, greater than, or less than the base data. In this process in a relational information display, both internal and external information is involved.
    - In the case of comparison (=), there is only external information. The information seeker simply needs to match the number, color, shape or other symbols. Since these are externally represented, internal memory is not a factor.
    - For the other cases of comparison (>,<), they must be minimally ordinal data in order to conduct the operation. There is an internal process used to decide if the target value is greater than or less than the base value. This is a more complicated process than localization and involves internal processing.

- *Calculation* is a cognitive process through which a number is manipulated by addition, subtraction, multiplication or division.
    - For calculation (+,-), it requires internal information and at least an interval data scale.
    - For calculation (x,/), it requires more internal information than calculation (+,-) because it is determined by the nature of the calculation. Also, the operations (x,/) can theoretically be transformed into calculation (+,-).

Depending on the data scale type of questions, some search questions are not qualified for all types of operations. For example, calculation is only applicable to interval and ratio questions. For interval questions, only addition and subtraction are involved. For ratio questions, addition, subtraction, multiplication and division may be allowed. A summary of question types along with their allowable operations is shown in Table 1.

Table 1. Question Type Based on Search Data Scales

Question type	Operation	Allowable Data Scale
Nominal	Localization, comparison (=)	Nominal, ordinal, interval, ratio
Ordinal	Localization, comparison (=,>,<)	Ordinal, interval, ratio
Interval	Localization, comparison (=,>,<), calculation (+,-)	Interval, ratio
Ratio	Localization, comparison (=,>,<), calculation (+,-,x,/)	Ratio

For a one-dimensional search, the process of localization is conducted on a one-base dimension. For a two-dimensional search, the process of localization is conducted on two-base dimensions. The types of questions can be downgraded from higher data scales to lower ones. For example, if a question is presented in ratio data scale, then this question could be transformed and downgraded into lower data scales such as interval, ordinal and nominal (Ratio>Interval>Ordinal>Nominal). Likewise, if an interval question is posed, the transformation could be Interval>Ordinal>Nominal, etc.

SUMMARY

The *UFuRT* process serves as a guideline for a human-centered information system design. Cognitive factors are my concern in the studies to improve information search efficiency. The taxonomy presents the basic understanding of distributed information search and its relations with other existing information models. The search task model further uncovers the hierarchical structure of a relational data search task. These presentations are the basis of the theoretical analysis and experimental designs presented in the next chapter.

CHAPTER III

THEORETICAL ANALYSES

In this chapter the theories upon which this study is based are laid out in more detail. This chapter also presents a pilot study that was conducted to assess the feasibility of using the *UFURT* process for experimental designs.

TASK ANALYSIS FOR SEARCH TASKS IN THREE TYPES OF INTERFACES

According to the theories described in chapter II, I conducted a couple of analyses so as to achieve a better understanding of search performance in different representations in terms of interaction of internal and external information. Typical search tasks in this research require both internal and external information. For example, a nominal search task in a one-dimensional search can be: "Is there an abnormal cholesterol value in the patient's record?" For answering this question, the internal information required is the normal cholesterol range (<200mg/dL), if it is not shown on the interface. The observed values on the patient's chart are the external information provided. The interaction of the internal and external information may result in nominal scale data; i.e., a "yes or no" answer. In a similar way, other search tasks require the operations in ordinal, interval or ratio scales.

In the pilot study, tasks of dimensional search, relational search, and within-dimension search were conducted with three prototypes (Zhang, 1996).

The three prototypes I developed are based on some EHR systems and have both holistic views and separate views. The holistic view carries 12-month health data while the separate view contains two 6-month health data spreads on separate pages. In order to browse or compare the values between the first six months and second six months, a physician would have to memorize the displayed values. Therefore, the information search process requires internal information not represented by the design of the interface. Likewise, the graphic view and mixed view both have holistic and separate subtypes. Because of the different representations, the search method for the same task in a text display is dissimilar to that in a graph representation. For example, when searching for the patient's heaviest weight in a 12-month period in the graph or mixed representation, one may just need to look at the highest bar (point) in the graph to get the corresponding month value. Consequently, this type of task may be more easily seen in a graph display than in a text display (see Step 4 in Figure 4 for details).

Figure 4 indicates the three types of representations, which are a table, a graph and a mixed display. For each of them, there are two subtypes, which are holistic view and separate view.

For each task with different scales, a detailed analysis reveals the complexity. According to representational effects, a good representation lies in the place where represented dimensions and representing dimensions match each other at the scale level.

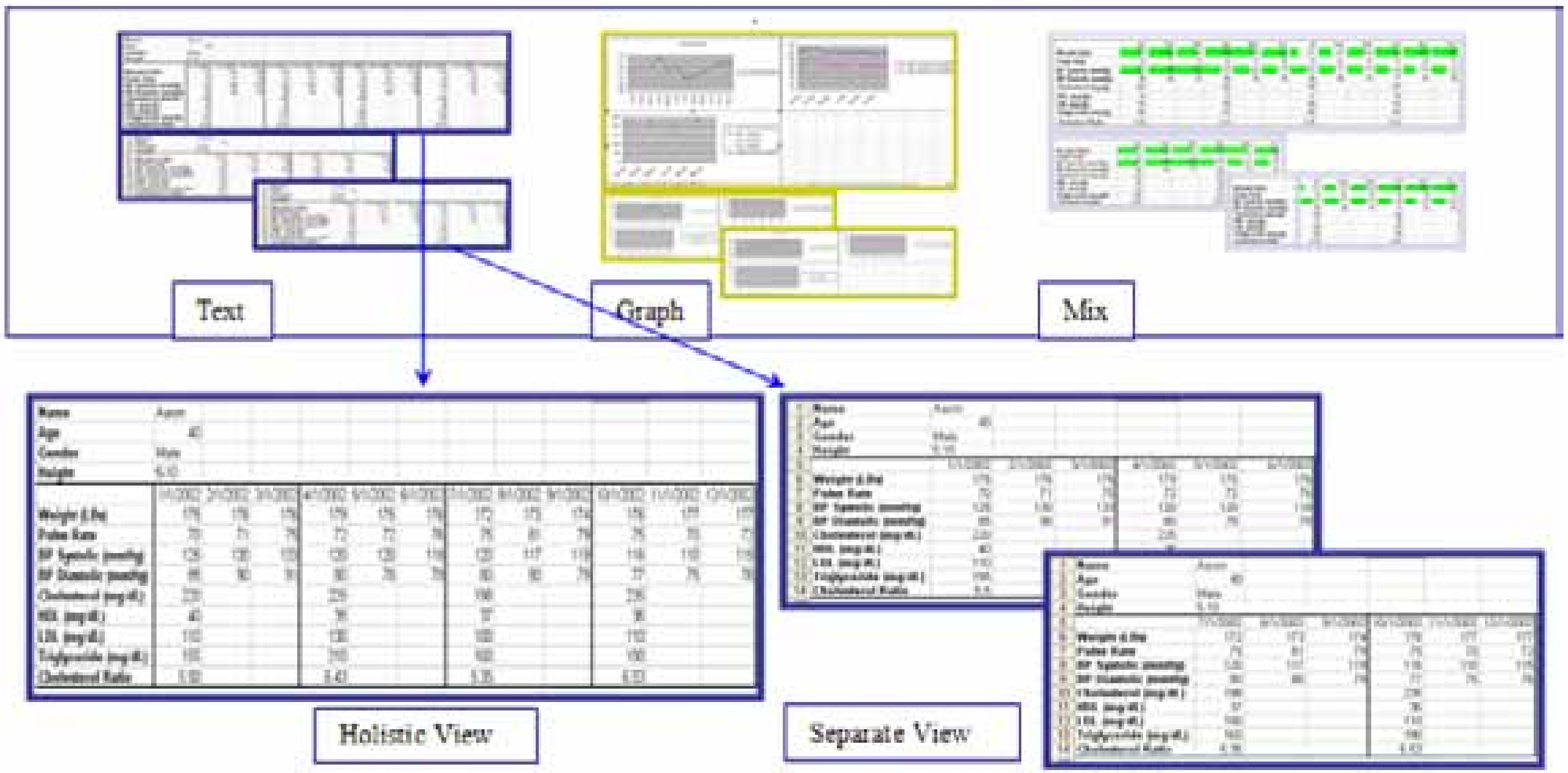


Figure 5. Three types of interfaces with holistic view and separate view

Preliminary Results of the Pilot Study

Employing the *UFuRT* theoretical frame to information search tasks for presentations, I have investigated three types of search tasks performed on three representations. Table 2 shows the task analysis results, including task steps and the internal/external information requirement. It not only explains the complexity of each search task but also describes the search performance on each interface. For instance, Task II takes the most steps on average and Task II's internal/external ratio is also the highest in the graph interface. Thus, according to this analysis, Task II is the hardest search task among the three.

A series of experiments on search tasks differentiated by data scales were designed. The purpose is to reveal the pattern difference on presentations between scale types in an information search. Most importantly, they examine the analyses based on the *UFuRT* design and evaluation framework.

Table 2. Task Analysis of Three Tasks in Three Types of Interfaces

Steps Internal/External = Ratio	Text		Graph		Mixed	
	Holistic	Separate	Holistic	Separate	Holistic	Separate
Task I	26	27	3-15	7-21	4-26	6-28
Are there any abnormal levels of cholesterol in the patient record?	14/12=1.17	14/13=1.07	½=0.50	¾=0.75	2/2=1.00	2/4=0.50
Task II	28	29	4-27	8-33	5-40	8-44
In which month of 2003 was the patient's LDL level abnormal?	15/13=1.15	15/14=1.07	2/2=1.00	3/5=0.80	2/5=0.40	2/6=0.33
Task III	24	26	2	3	4	5
Has the patient's triglyceride level dropped since the start of his diet treatment?	12/12=1.00	12/14=0.86	0/2=0	0/3=0	0/4=0	0/5=0

THEORETICAL ANALYSES FOR DIMENSIONAL SEARCHES

The section presents theoretical analyses of dimensional search tasks which are described in the search task taxonomy. The analyses provide the comparisons of user search performances when conducted on table and graph displays. I notice that in some instances, information presented on the display does not provide enough power to complete the search tasks, whereas in other cases, the information presented on the display provides more than enough power for the search tasks. These situations are also described in detail with examples. Applying the theoretical framework to relational data searches, one dimension and two dimension searches in table and graph displays are also analyzed and compared.

Theoretical Analysis of Graph and Table Displays

The following case analysis (Figure 6) explains why the graph display is better than the table display when the three-operation taxonomy was employed to analyze the search task of an interval question.

For each operation of the search, the complexity can be measured by internal and external information requirements in each task step.

In the table display for a nominal question shown in Figure 6, the localization process involves external information, and the process is composed of two stages. The first stage is to locate the target row. Since the name of the variable is presented in the table (within Figure 6), this stage involves only external information. Once the target row is identified, the next stage is to find the target value in the row, which is a repeated action from column one to column N. All the values are presented in the table. Thus, this search is also considered external information. For example, “Was there any value of cholesterol at 200mg/dL in this chart?” The task analysis in Table 3 shows that the search strategy in the table display is more complicated than the one in the graph, though the search information requirements are all external information.

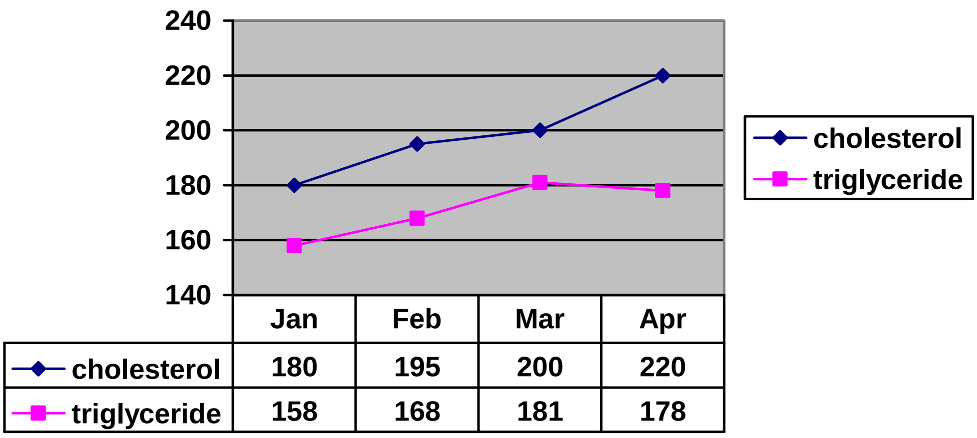


Figure 6. A sample of display for search task analysis for the table display and the graph display

Employing the same task analysis methods, the graph displays are superior to the table displays for nominal, ordinal, interval and ratio questions. From the analysis above, I predict that in the one dimension search, the graph displays have a better efficiency than do the tables. Theoretically, this prediction also applies to the two-dimension search.

Table 3. A Comparison of Search Strategies on the Table and Graph Displays for a Nominal Task

Step	For searching a table display:	For searching a graph display:
1	Locate the target row based on the question	Identify the legend for the target graph
2	Locate the Nth (n from 1 to m) cell value in the target row m is the total number of columns	Locate the Y axis for the base value on the target graph
3	If cell value= base value then answer= “Yes”	Scan the graph horizontally on the base value level
4	If cell value<>base value then return to step 2, n++	If there is a value on horizontal level then answer = “Yes”
5	If last cell value (n=m) is checked, the answer= “No”	If there is no value on horizontal level then answer = “No”
6	Minimum steps=1,2,3 (3 steps)	
7	Maximum steps=3 steps + number of cells in the target row	

For each type of question, there is a set of allowable operations which are listed in Table 4. A nominal question basically locates the answer represented on a display. An ordinal question involves localizing and comparing the data on some display. An interval question has all the properties that a nominal and an ordinal question have, and in addition, allows the calculations of addition and subtraction. The most comprehensive question type is a ratio question, which not only involves the properties of nominal, ordinal and interval questions but also allows for the calculations of multiplication and division.

For a display, there is also a set of allowable operations which is defined by the display of the data scales. The detailed information on the two dimensions of data display and question is indicated in Table 4.

Over-representation and Under-representation

Ideally, the data display and question should match each other on the data scale level. However, there are two concepts, over-representation and under-representation, used to describe a situation in which the display and the question do not exactly match. For example, a nominal display provides sufficient information for a nominal question. Once further information beyond the nominal scale is placed on the display, this information is referred to as over-representation. On the other hand, if a ratio question is asked in a nominal display, the nominal data does not provide enough information to answer the question, and the information is referred to as under-representation. Over-representation in the data scale may decrease the search efficiency due to the extra information, whereas under-presentation fails to answer the question due to the lack of data power in terms of data scales. Figure 7 illustrates the over-representation (information overload) and under-representation (information missed).

Theoretically, the diagonal line in the table is the perfect match between the type of search task and scale representations. The area above the diagonal line carries the extra amount of information which increases the cognitive workload. The area below the line does not provide enough information to perform the search task.

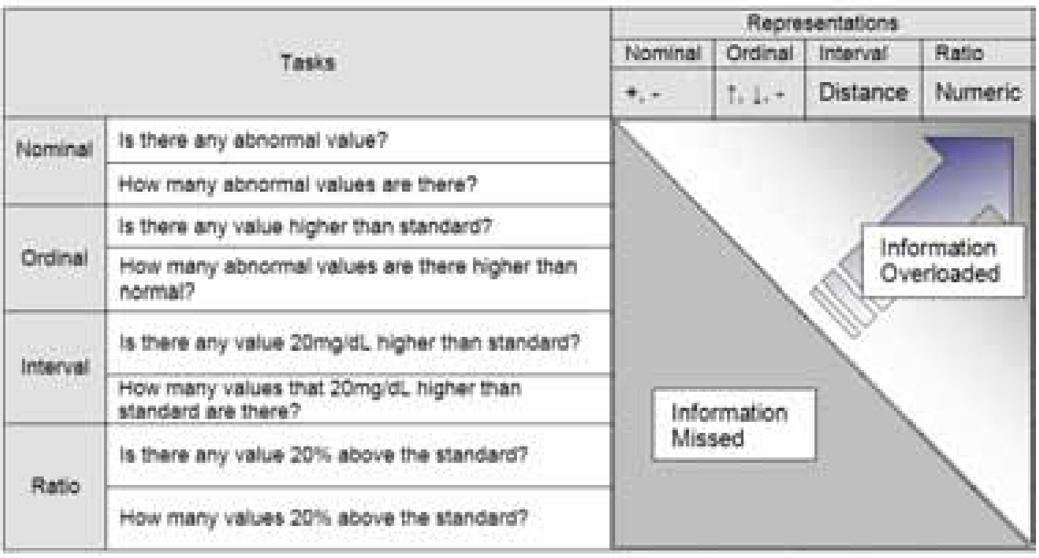
Table 4. The Properties of Scales and Question Types

Data Display	Question			
Ratio	Nominal Localization Comparison (=)	Ordinal Localization Comparison (=)	Interval Localization Comparison (=,>,<) Calculation (+,-)	Ratio Localization Comparison (=,>,<) Calculation (+,-,x,/)
Interval	Nominal Localization Comparison (=)	Ordinal Localization Comparison (=)	Interval Localization Comparison (=,>,<) Calculation (+,-)	
Ordinal	Nominal Localization Comparison (=)	Ordinal Localization Comparison (=)		
Nominal	Nominal Localization Comparison (=)			

Search Tasks and Their Expansions

In order to examine the relationship between question types and data display based on scale types, I developed a set of nominal, ordinal, interval and ratio questions/tasks and they were used to test the search performance when in different representations.

A nominal question/task is for locating a target. In this study, I take relational data as an example. Thus, the target is a value of the data. The question could be “Is there any abnormal value in the chart?” To answer this question, the process is required to locate any abnormal value, and the answer is either yes or no. A more complicated version of the nominal question is “How many abnormal values are there?”, which requires a summation of the yes or no answers. These two types of questions for nominal questions/tasks are also applicable to ordinal, interval, and ratio questions/tasks. A list of example questions is depicted in Figure 7.



Tasks		Representations: Nominal +, -	Representations: Ordinal ↑, ↓, -	Representations: Interval Distance	Representations: Ratio Numeric
Nominal	Is there any abnormal value?				
	How many abnormal values are there?				
Ordinal	Is there any value higher than standard?				
	How many abnormal values are there higher than normal?				
Interval	Is there any value 20mg/dL higher than standard?				
	How many values that 20mg/dL higher than standard are there?				
Ratio	Is there any value 20% above the standard?				
	How many values 20% above the standard?				

Figure 7. Samples of matching search tasks and representing dimensions

One-Dimensional Search

A one-dimensional search is defined as an information search which requires examining the data in one row/column of a table, or one variable in a graph.

As discussed above, a one-dimensional search contains nominal, ordinal, interval and ratio searches. Table 5, Table 6, Table 7, Table 8, and Table 9 present each type of search in the format of formula, abstract tasks, and concrete examples.

Table 5. A Task Analysis for a One-dimensional Nominal Question of the Relational data

Nominal Question, One-dimensional Search (1D-NS)		
Abstract Operation	1D-NS (target table value = normal value)	
Operation in General	Locate the target dimension and compare the values to base value (normal value), and check to determine if they are equal.	
Sample Question	Was there any value of cholesterol at 200mg/dL?	
Display	For searching a table display	For searching a graph display
Steps	1. locate the target row based on the question 2. locate the Nth (n from 1 to m) cell value in the target row, m is the total number of columns. 3. if cell value= base value then answer= “Yes” 4. if cell value<>base value then return to step 2, n++ 5. if last cell value (n=m) is checked, the answer= “No”	1. identify the legend for the target graph 2. locate the Y axis for the base value on the target graph 3. scan the graph horizontally on the base value level 4. if a value is on that level then answer = “Yes” 5. if no value is on that level then answer = “No”
Min/Max Steps	Minimum steps=1,2,3 (3 steps) Maximum steps=3 steps + number of cells in the target row	maximum=minimum=5 steps

Table 6. A Task Analysis for a One-dimensional Ordinal Question of the Relational data

Ordinal Question, One-dimensional Search (1D-OS)		
Abstract Operation	1D-OS (target table value > normal value)	
Operation in General	Locate the target dimension and compare the values to base value (normal value) and check to determine if they are greater than the base value	
Sample Question	Was there any value of cholesterol greater than 200mg/dL?	
Display	For searching a table display	For searching a graph display
Steps	1. locate the target row based on the question 2. locate the Nth (n from 1 to m) cell value in the target row 3. if cell value>base value then answer= "Yes" 4. if cell value<=base value then return to step 2, n++ 5. if last cell value (n=m) is checked, the answer= "No	1. identify the legend for the target graph 2. locate the Y axis for the base value on the target graph 3. scan the graph horizontally above the base value level 4. if a value is on that level then answer = "Yes" 5. if no value is on that level then answer = "No"
Min/Max Steps	Minimum steps=1,2,3 (3 steps) Maximum steps=3 steps + number of cells in the target row	maximum=minimum=5 steps

Table 7. A Task Analysis for a One-dimensional Interval Question of the Relational data

Interval Question 1, One-dimensional Search(1D-IS)		
Abstract Operation	1D-IS (target table value = normal value+50)	
Operation in General	Locate the target dimension and compare the values to base value (normal value) plus a parameter (a number).	
Sample Question	Was there any value of cholesterol more than 50mg/dL beyond 200mg/dL?	
Display	For searching a table display	For searching a graph display
Steps	1. locate the target row based on the question 2. locate the Nth (n from 1 to m) cell value in the target row 3. if cell value= (base value+ parameter N) then answer= “Yes” 4. if cell value<> (base value+ parameter N) then return to step 2, n++ 5. if last cell value (n=m) is checked, the answer= “No”	1. identify the legend for the target graph 2. locate the Y axis for the base value plus the parameter N on the target graph 3. scan the graph horizontally above the base value level 4. if a value is on that level then answer = “Yes” 5. if no value is on that level then answer = “No”
Min/Max Steps	Minimum steps=1,2,3 (3 steps) Maximum steps=3 steps + number of cells in the target row	maximum=minimum=5 steps

Table 8. A Task Analysis for another One-dimensional Internal Question of the Relational data

Interval Question 2 (more complicated version)		
Abstract Operation	1D-Ratio (target table value1 - target table value 2 = 50)	
Operation in General	Locate the target dimension and calculate the difference between the two values, then check to determine if it equals a parameter (number).	
Sample Question	Was there any pair of cholesterol values with a difference of 50mg/dL?	
Display	For searching a table display	For searching a graph display (bar chart or discrete line chart in this case, for continuous line chart, measure the difference between lowest and highest point. If the difference > parameter, answer is yes, otherwise, no)
Steps	1. locate the target row based on the question 2. locate the Nth (n from 1 to m) cell value in the target row (m is the total number of columns) 3. locate the Kth+1 cell (K from n+1 to m) value in the target row, K++ 4. if Nth cell value= (Nth+1	1. identify the legend for the target graph 2. locate the Y axis for the lowest value L on the target graph 3. locate the Y axis for the highest value H on the target graph 4. if highest value- lowest value < parameter then

	cell value+/- parameter N) then answer= “Yes” 5. if Nth cell value<> (Nth+1 cell value+/- parameter N) then return to step 2, n++ 6. if last cell value (n=m & k=m)) is checked, then answer= “No”	answer= “No” 5. if highest value- lowest value = parameter then answer= “Yes” 6. if highest value- lowest value > parameter then 7. locate the Y axis for i= second lowest value to m; i++ 8. locate the Y axis for j=i+1th lowest value to m; j++ 9. if j-i = parameter, then answer= “Yes” 10. otherwise answer = “No”
Min/Max Steps	Depends	Minimum steps=4 Maximum steps= C (m,2)+4; C (m,n)=M!/{n! (m-n)!}G

Table 9. A Task Analysis for a One-dimensional Ratio Question of the Relational data

Ratio Question, One-dimensional Search (1D-RS)		
Abstract Operation	1D-RS (target table value = normal value (1+20%))	
Operation in General	Locate the target dimension and calculate the ratio of the target value over base value, then check to find if it equals a parameter (percentage)	
Sample Question	Was there any value of cholesterol 20% above 200mg/dL?	
Display	For searching a table display	For searching a graph display
Steps	If calculating what the final parameter is, this type of question is then converted to a nominal question. See "nominal" for details. If calculating the ratio during each comparison, this type of question is then converted to an interval question. See "Interval 1" for details.	If calculating what the final parameter is, this type of question is then converted to a nominal question. See "nominal" for details. If calculating the ratio during each comparison, this type of question is then converted to an interval question. See "Interval 1" for details.
Min/Max Steps	Depends	Depends

The analysis indicates that searching the same type of question by table and graph displays requires different strategies and various steps. This analysis helps explain the complexity and the user performance in one-dimensional search tasks.

Two-Dimensional Search

A two-dimensional search is defined as an information search which requires examining the data in two rows/columns of a table, or two variables in a graph.

Two-dimensional searches contain nominal, ordinal, interval, and ratio searches. The following Tables 10, 11, 12, 13, 14, and 15 describe the definitions of each type of search in the format of formula, abstract tasks, and concrete examples.

Table 10. A Task Analysis for a Two-dimensional Nominal Question of the Relational data

Nominal Question, Two-dimensional Search Within (2D-NS_w)		
Abstract Operation	2D-NS_w (target table value in month 1=?)	
Operation in General	Locate the intersection of two target dimensions, and find out the target value	
Sample Question	What was the value of cholesterol in January?	
Display	For searching a table display	For searching a graph display
Steps	1. locate the target row based on the question (cholesterol in this question) 2. locate the target column (time) based on the question (month in this question) 3. locate the target cell in the column 4. get the value at the intersection of target column and row	1. identify the legend for the target graph 2. locate the X axis for the target time 3. locate the value on target graph 4. get the value on the Y axis
Min/Max Steps	Depends	Depends

Table 11. A Task Analysis for a Two-dimensional Ordinal Question of the Relational data

Ordinal Question 1, Two-dimensional Search Within (2D-OS_w)		
Abstract Operation	2D-OS_w (target table value in month 1 > normal value?)	
Operation in General	Locate the intersection of two target dimensions, and compare the target value with base value	
Sample Question	Was the value of cholesterol in January greater than 200mg/dL?	
Display	For searching a table display	For searching a graph display
Steps	1. locate the target row based on the question (cholesterol in this question) 2. locate the target column (time) based on the question (month in this question) 3. locate the target cell in the column 4. get the value at the intersection of target column and row 5. if target value = base value (200mg/dL) then answer= "Yes" 6. Otherwise answer= "No"	1. For searching a graph display: 2. identify the legend for the target graph 3. locate the X axis for the target time 4. locate the value on target graph 5. get the target value on the Y axis 6. if target value above base value (200mg/dL) on Y axis then answer= "Yes" 7. Otherwise answer= "No"
Min/Max Steps	Depends	Depends

Table 12. A Task Analysis for another Two-dimensional Ordinal Question of the Relational data

Ordinal Question 2, Two-dimensional Search Within (2D-OS_w)		
Abstract Operation	2D-OS_w (target table value in month 1 > target table value in month 2)	
Operation in General	Locate the intersection of two target dimensions, and compare the two target values then check which target value is greater.	
Sample Question	Was the value of cholesterol in January greater than that of June?	
Display	For searching a table display	For searching a graph display
Steps	locate the target row based on the question (cholesterol in this question) locate the target column 1 (time 1) based on the question (month in this question) locate the target cell 1 in the column get the target value 1 at the intersection of target column 1 and row locate the target column 2 (time 2) based on the question locate the target cell 2 in the column get the target value 2 at the intersection of target column 2 and row if target value 1 > target value 2 then answer= “Yes”	identify the legend for the target graph locate the X axis for the target time 1 get the position of target value 1 locate the X axis for the target time 2 get the position of target value 2 if target value 1 is above target value 2 then answer= “Yes” otherwise answer= “No”

	otherwise answer= “No”	
Min/Max Steps	Depends	Depends

Table 13. A Task Analysis for a Two-dimensional Interval Question of the Relational data

Interval Question 1, Two-dimensional Search Within (2D-IS_w)		
Abstract Operation	2D-IS_w (target table value in month 1 -month 2 <> target table value in month 3-month 4)	
Operation in General	Locate the intersection of two target dimensions, and calculate the difference of two target values, then calculate the difference of another two target values, and finally compare the two differences to check which is greater	
Sample Question	Does the change of cholesterol values between January and June equal that between February and July?	
Display	For searching a table display	For searching a graph display
Steps	1. locate the target row based on the question (cholesterol in this question) 2. locate the target column 1 (time 1) based on the question (month in this question) 3. locate the target cell 1 in the column 4. get the target value 1 at the intersection of target column 1 and row 5. locate the target column 2 (time 2) based on the question 6. locate the target cell 2 in the column 7. get the target value 2 at the	1. identify the legend for the target graph 2. locate the X axis for the target time 1 3. get the position of target value 1 4. locate the X axis for the target time 2 5. get the position of target value 2 6. measure the difference (D1) between target value 1 and 2 7. repeat step 2, 3, 4, 5, 6 (for target time 3 and 4 and measure D2) 8. if D1 = D2 then answer= “Yes”

		intersection of target column 2 and row 8. calculate the difference (D1) between target value 1 and target value 2 9. repeat step 2, 3, 4, 5, 6, 7 (for column 3 and 4) 10. calculate the difference (D2) between target value 3 and target value 4 11. if D1 = D2 then answer= "Yes" 12. otherwise answer= "No"	9. otherwise answer= "No"
Min/Max Steps		Depends	Depends

Table 14. A Task Analysis for Another Two-dimensional Ordinal Question of the Relational data

Interval Question 2, Two-dimensional Search Within (2D-IS_w)		
Abstract Operation	2D-IS_w (target table value in month 1 -month 2 = 50?)	
Operation in General	Locate the intersection of two target dimensions, and calculate the difference of the two target values, then check if it equals a parameter (number)	
Sample Question	Is the difference in cholesterol between January and June greater than 50mg/dL?	
Display	For searching a table display	For searching a graph display
Steps	1. locate the target row based on the question (cholesterol in this question)	1. identify the legend for the target graph 2. locate the X axis for the

	2. locate the target column 1 (time 1) based on the question (month in this question) 3. locate the target cell 1 in the column 4. get the target value 1 at the intersection of target column 1 and row 5. locate the target column 2 (time 2) based on the question 6. locate the target cell 2 in the column 7. get the target value 2 at the intersection of target column 2 and row 8. if target value 1 - target value 2 > base value (50mg/dL in this case) then answer= “Yes” 9. otherwise answer= “No”	target time 1 3. get the position of target value 1 4. locate the X axis for the target time 2 5. get the position of target value 2 6. if target value 1 is above target value 2 for the base value length (height) then answer= “Yes” 7. otherwise answer= “No”
Min/Max Steps	Depends	Depends

Table 15. A Task Analysis for a Two-dimensional Ratio Question of the Relational data

Ratio Question, Two-dimensional Search Within (2D-RS_w)		
Abstract Operation	2D-RS_w (target table value in month 1 =normal value (1+20%))	
Operation in General	Locate the intersection of two target dimensions, and calculate the ratio of the target value over the base value, then check to determine if it equals a parameter (percentage)	
Sample Question	Was the value of cholesterol in January greater than that of June by 20%?	
Display	For searching a table display	For searching a graph display
Steps	Can be converted into (greater than ??mg/dL) as shown above.	Can be converted into (greater than ??mg/dL) as shown above.
Min/Max Steps	Depends	Depends

According to representational theory, represented and representing dimensions have to match each other at the data scale level so as to achieve a good efficiency for the representations. Table 16Table 17,Table 18, Table 19 explain the analysis of each type of search task in terms of task complexity and dimensional matches.

Table 20 summarizes the search task taxonomy. The two major categories are direct search and comparative search. Direct searches can be further divided into dimensional and relational searches. Comparative searches, it can be further stratified into within-dimensional and between-dimensional searches. The taxonomy serves as a nomenclature for relational data search tasks and helps clarify the task complexity and find the appropriate data representations. Table 21 presents the taxonomy with definitions and instances.

Some matching tasks were selectively chosen from these tables for my empirical studies which are described in the next chapter.

Table 16. Mapping Represented and Representing Dimensions with Search Tasks in Data Scales - Nominal

Nominal Tasks								
R-ed	R-ing	R-ed & R-ing Scale Property Match	Feasibility	R-ed & Task Scale (Nominal) Match	R-ed & Task Match	R-ing & Task Scale (Nominal) Match	R-ing & Task Match	Perfect Match
N	N	1	Yes	1	High	1	High	Yes
N	O	1	No	1		1		
N	I	1	No	1		1		
N	R	1	No	1		1		
O	N	1	Yes	1	Medium	1	High	
O	O	2	Yes	1	Medium	1	Medium	
O	I	2	No	1		1		
O	R	2	No	1		1		
I	N	1	Yes	1	Low	1	High	
I	O	2	Yes	1	Low	1	Medium	
I	I	3	Yes	1	Low	1	Low	
I	R	3	No	1		1		
R	N	1	Yes	1	Very Low	1	High	
R	O	2	Yes	1	Very Low	1	Medium	
R	I	3	Yes	1	Very Low	1	Low	
R	R	4	Yes	1	Very Low	1	Very Low	

Table 17. Mapping Represented and Representing Dimensions with Search Tasks in Data Scales - Ordinal

Ordinal Tasks								
R-ed	R-ing	R-ed & R-ing Scale Property Match	Feasibility	R-ed & Task Scale (Ordinal) Match	R-ed & Task Match	R-ing & Task Scale (Ordinal) Match	R-ing & Task Match	Perfect Match
N	N	1	Yes	1	Poor	1	Poor	
N	O	1	No	1		2		
N	I	1	No	1		2		
N	R	1	No	1		2		
O	N	1	Yes	2	High	1	Poor	
O	O	2	Yes	2	High	2	High	Yes
O	I	2	No	2		2		
O	R	2	No	2		2		
I	N	1	Yes	2	Medium	1	Poor	
I	O	2	Yes	2	Medium	2	High	
I	I	3	Yes	2	Medium	2	Medium	
I	R	3	No	2		2		
R	N	1	Yes	2	Low	1	Poor	
R	O	2	Yes	2	Low	2	High	
R	I	3	Yes	2	Low	2	Medium	
R	R	4	Yes	2	Low	2	Low	

Table 18. Mapping Represented and Representing Dimensions with Search Tasks in Data Scales - Interval

Interval Tasks								
R-ed	R-ing	R-ed & R-ing Scale Property Match	Feasibility	R-ed & Task Scale (Interval) Match	R-ed & Task Match	R-ing & Task Scale (Interval) Match	R-ing & Task Match	Perfect Match
N	N	1	Yes	1	Poor	1	Poor	
N	O	1	No	1		2		
N	I	1	No	1		3		
N	R	1	No	1		3		
O	N	1	Yes	2	Poor	1	Poor	
O	O	2	Yes	2	Poor	2	Poor	
O	I	2	No	2		3		
O	R	2	No	2		3		
I	N	1	Yes	3	High	1	Poor	
I	O	2	Yes	3	High	2	Poor	
I	I	3	Yes	3	High	3	High	Yes
I	R	3	No	3		3		
R	N	1	Yes	3	Medium	1	Poor	
R	O	2	Yes	3	Medium	2	Poor	
R	I	3	Yes	3	Medium	3	High	
R	R	4	Yes	3	Medium	3	Medium	

Table 19. Mapping Represented and Representing Dimensions with Search Tasks in Data Scales - Ratio

Ratio Tasks								
R-ed	R-ing	R-ed & R-ing Scale Property Match	Feasibility	R-ed & Task Scale (Ratio) Match	R-ed & Task Match	R-ing & Task Scale (Ratio) Match	R-ing & Task Match	Perfect Match
N	N	1	Yes	1	Poor	1	Poor	
N	O	1	No	1		2		
N	I	1	No	1		3		
N	R	1	No	1		4		
O	N	1	Yes	2	Poor	1	Poor	
O	O	2	Yes	2	Poor	2	Poor	
O	I	2	No	2		3		
O	R	2	No	2		4		
I	N	1	Yes	3	Poor	1	Poor	
I	O	2	Yes	3	Poor	2	Poor	
I	I	3	Yes	3	Poor	3	Poor	
I	R	3	No	3		4		
R	N	1	Yes	4	High	1	Poor	
R	O	2	Yes	4	High	2	Poor	
R	I	3	Yes	4	High	3	Poor	
R	R	4	Yes	4	High	4	High	Yes

Table 20. A Taxonomy of Information Search Tasks in Relational Information Display

	Direct Search		Comparative search	
	Dimensional Search	Relational Search	Within-dimension	Between-dimension
Definition	Search for values on one dimension	Search for values on multiple dimensions	Compare values within one dimension	Compare values between multiple dimensions
Example	1. Are there any abnormal levels of cholesterol in the patient's record? -search data within one dimension 2. How many times was the patient's diastolic pressure recorded as abnormal? -an extended question based on Example I, counting the abnormal numbers becomes part of the dimensional search	1. In which month of 2003 was the patient's LDL level abnormal? -search data within two dimensions 2. Was there any date during 2003 when both HDL and triglyceride were abnormal? -search data with three dimensions 3. What were other laboratory values on the lipid panel when the HDL was abnormal? -search data within multiple dimensions	Has the patient's triglyceride level dropped since the start of his diet treatment? - to detect trends of data distribution	Has the cholesterol ratio (total cholesterol/HDL) changed over the past year? - calculation involved

Table 21. A Relational data Search Taxonomy with Definitions and Instances

Taxonomy		Definitions	Instances
One-dimensional search:			
Nominal	1D-NS (target table value = normal value)	Locate the target dimension and compare the values to base value (normal value), and check to determine if they are equal.	Was there any value of cholesterol at 200mg/dL?
Ordinal	1D-OS (target table value > normal value)	Locate the target dimension and compare the values to base value (normal value), and check to determine if they are greater than the base value.	Was there any value of cholesterol greater than 200mg/dL?
Interval	1D-IS (target table value = normal value+50)	Locate the target dimension and compare the values to base value (normal value) plus a parameter (a number).	Was there any value of cholesterol more than 50mg/dL beyond 200mg/dL?
	1D-Ratio (target table value1 - target table value 2 = 50)	Locate the target dimension and calculate the difference of two values, then check to determine if it equals a parameter (number).	Was there any pair of cholesterol values difference 50mg/dL?
Ratio	1D-Ratio (target table value = normal value (1+20%))	Locate the target dimension and calculate the ratio of the target value over base value, then check to determine if it equals a parameter (percentage).	Was there any value of cholesterol 20% above 200mg/dL?
	Relational search – within dimension		

Taxonomy		Definitions	Instances
Nominal	2D-NS_w (target table value in month 1=?)	Locate the intersection of two target dimensions and find out the target value	What was the value of cholesterol in January?
Ordinal	2D-OS_w (target table value in month 1 > normal value?)	Locate the intersection of two target dimensions, and compare the target value with the base value	Was the value of cholesterol in January greater than 200mg/dL?
	2D-OS_w (target table value in month 1 > target table value in month 2?)	Locate the intersection of two target dimensions and compare the two target values, then check which target value is greater.	Was the value of cholesterol in January greater than that of June?
Interval	2D-IS_w (target table value in month 1 - month 2 <> target table value in month 3-month 4)	Locate the intersection of two target dimensions, calculate the difference of two target values, then calculate the difference of another two target values, and finally, compare the two differences to check which is greater	Does the change cholesterol between January and June equal that between February and July?
	2D-IS_w (target table value in month 1 - month 2 = 50?)	Locate the intersection of two target dimensions, calculate the difference of the two target values, then check to find if it equals a parameter (number).	Is the difference in cholesterol values between January and June greater than 50mg/dL?
Ratio	2D-Ratio_w (target table value in month 1 =normal value (1+20%))	Locate the intersection of two target dimensions, calculate the ratio of the target value over the base value, then check to see if it equals a parameter (percentage).	Was the value of cholesterol in January 20% greater than that of June?

Taxonomy		Definitions	Instances
Relational search – between dimensions			
Nominal	2D-NS_b (systolic BP - diastolic BP > 40?)	Locate the target dimensions in one column, and calculate the difference of the two, then determine if it equals a parameter (number).	Is there any difference between systolic blood pressure (BP) and diastolic BP greater than 40mmHg?
Ordinal	2D-OS_b (systolic BP in (diastolic BP <> normal value))	Locate the target dimensions in one column, compare to their base values respectively to decide their normality, then determine if there is a normal/abnormal pair.	Is there any normal systolic BP corresponding to an abnormal diastolic BP?
Interval	2D-IS_b (difference systolic/diastolic in month 1 = month 2)	Locate the first group of target dimensions in one column, calculate the difference between the two, then locate the second group of target dimensions and calculate the difference between the two. Compare the two differences to see if they are equal.	Does the difference in systolic/diastolic BP in January equal that in June?
Ratio	2D-Ratio_b (ratio of cholesterol/HDL <5:1)	Locate the two target dimensions; calculate the ratio of target value 1/ target value 2, then compare to the base parameter (ratio).	Is there any month in which the cholesterol ratio was greater than 5:1?

SUMMARY

The analyses in this chapter indicate that there are differences between table and graph displays in terms of search strategies and steps. In order to complete a search task, the displays must provide adequate information. Search tasks categorized by data scales may have different efficiencies for different displays. The search task taxonomy of relational data for a relational information display can be used as an analysis tool for revealing a task's nature and complexity.

CHAPTER IV

EXPERIMENTAL DESIGNS

Based on the theoretical analyses presented in previous chapters, this chapter presents my proposed hypotheses and the experimental designs for my empirical studies.

RESEARCH HYPOTHESES

In this research, I am interested in the internal and external information which plays an important role in search tasks of relational data. For a typical search task in my study, both internal and external information is needed in order to fulfill the task. According to the pilot study described in the Chapter III, the search steps and the requirements for internal and external information are different for search interfaces. It has been my interest to study the relationship between types of interfaces and types of search tasks in terms of effectiveness and efficiency for relational data searches.

Three specific hypotheses are evaluated here:

Hypothesis I: an information search with more external information yields a better task performance than one with less external information. This is because the information in external representations can be picked up by perceptual processes, whereas the information in internal representations has to be retrieved from memory.

Hypothesis II: Exact representations between task and data representation yield better performances than those of over-representations.

Hypothesis III: Two-dimensional searches are error-prone and more complex than one-dimensional searches.

This research study is of a within-subject experimental design, and compares the performances of each person with different information representations.

SUBJECTS

Approval to conduct this study was obtained from the Institutional Review Board (IRB), Committee for the Protection of Human Subjects at the University of Texas Health Science Center at Houston (Appendix A)

This study solicited a purposeful sample of 24 subjects from graduate schools within the Texas Medical Center. Subjects were recruited through advertisement (Appendix B) and formal and informal presentations. Adult subjects were recruited (ages 18 years and older) regardless of ethnicity and gender. Male and female subjects were equally recruited in this research study.

MATERIALS

Hypothetical data for adult's lipid panels were developed based on the normal lipid panel ranges provided by the American Heart Association (www.americanheart.org). A question pool was created and stored in an Excel sheet.

The hypothetical data for the experiments were then entered into Excel sheets. Microsoft Visual Basic for Applications (VBA) codes were used to implement the interface design and capture the response time and answers to each question.

Based on task analysis, I selectively implemented the following experimental interfaces.

1. For nominal search tasks, there are three types of interfaces, shown in Figure 8, Figure 9, and Figure 10. The purpose of this design was to test the user performance when searching answers in the representations of nominal, ordinal, and ration data scales. More examples of interfaces see Appendix E.

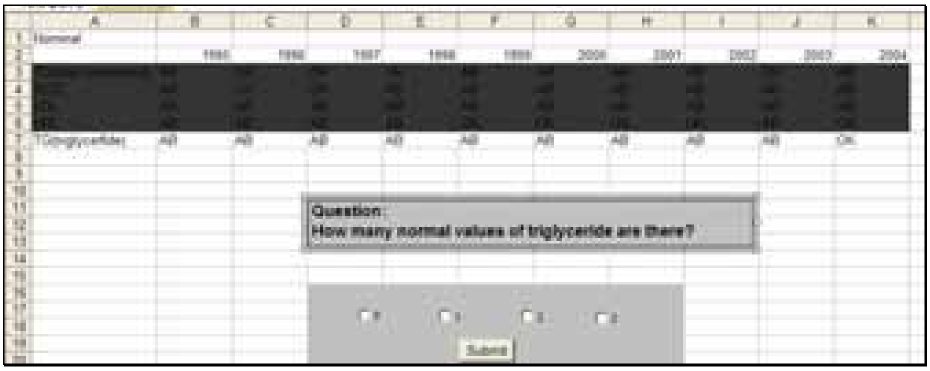


Figure 8. Nominal search interface for nominal questions

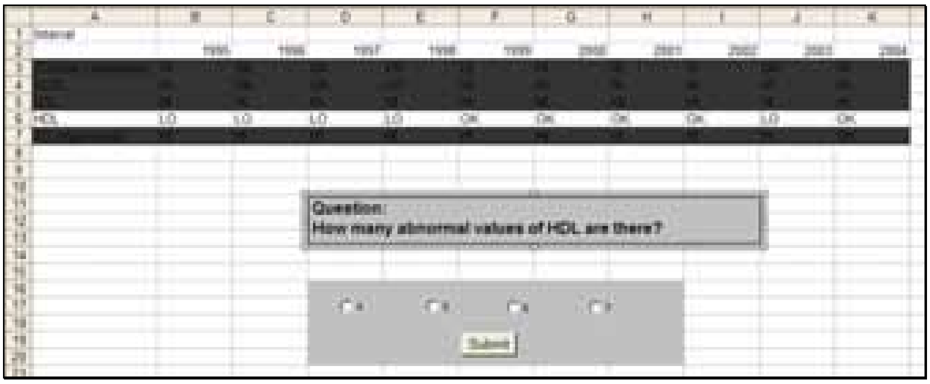


Figure 9. Ordinal search interface for nominal questions

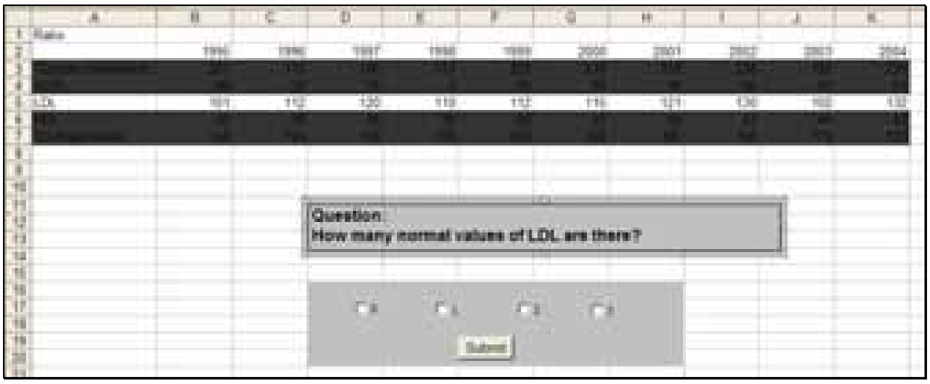


Figure 10. Ratio search interface for nominal questions

2. The hypothetical data were also represented in both tables and graphs. The purpose of this design was to test the different levels of external information provided by interfaces; such information is theoretically helpful in this type of searches.

3. On a representation with a ratio data scale, subjects were asked to answer four types of questions such as the following: "How many values of cholesterol are there at 210mg/dl?" (nominal question); "How many values of cholesterol are there greater than 200mg/dl?" (ordinal question); "How many values of cholesterol are there 20mg/dl higher than 200mg/dl?" (interval question);

"How many values of cholesterol are there 20% higher than 200mg/dl?" (ratio question). These four types of questions were asked in the form of both table representation and graph representation. The following two figures (Figure 11, Figure 12) illustrate a sample of ratio questions represented in a table and in a graph.

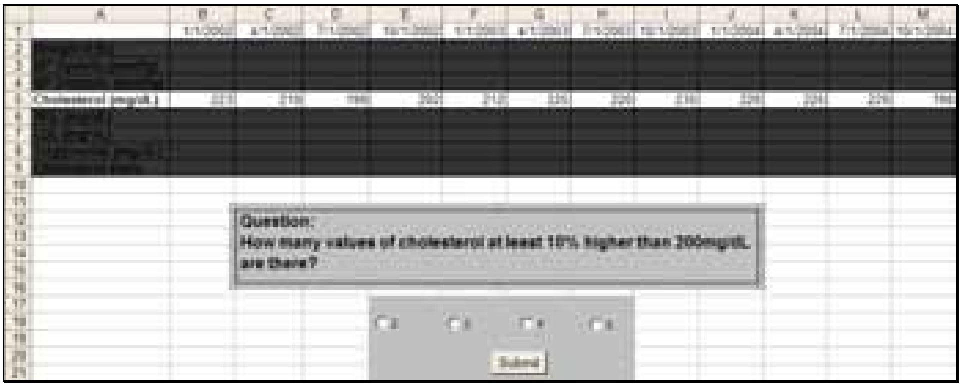


Figure 11. Ratio search interface – Table

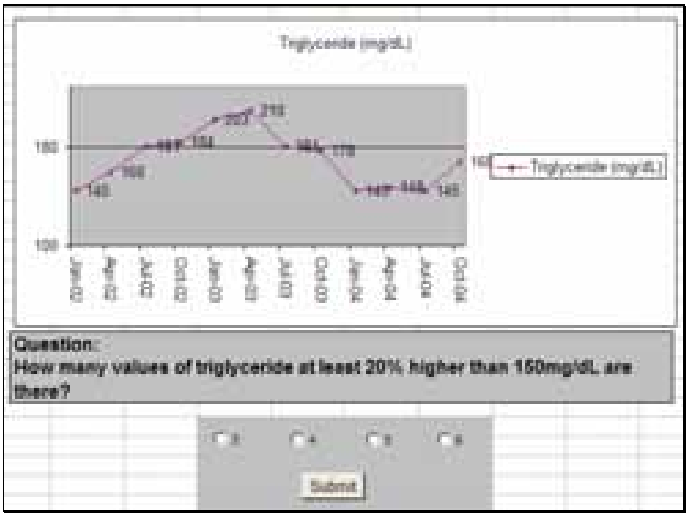


Figure 12. Ratio search interface – Graph

4. For representations with a ratio data scale, four types of questions were asked in two-dimensional methods; for example: "On which

following date was the value of cholesterol at 210mg/dl?" (nominal question); "On which following date was the value of cholesterol greater than 200mg/dl?" (ordinal question); "On which following date was the value of cholesterol 20mg/dl higher than 200mg/dl?" (interval question); "On which following date was the value of cholesterol 20% higher than 200mg/dl? "(ratio question).

Training Session

Employing the same technique described in the Material section, a training session was created for two purposes:

1. to inform subjects that they were expected to memorize all the normal ranges of a lipid panel so as to correctly answer each question in the tests.
2. to provide subjects an opportunity to get familiar with some sample questions from the test.

Response time and the correctness of each answer were recorded during this training session. Each subject had to correctly answer all the questions in order to proceed to the experiment.

DESIGN

Counter-balancing the Order Effect

To avoid possible sequential effects, counter-balancing methods were used. The questions and the choice sets were ordered so as to prevent participants from answering with information from previous trials.

In addition, three constraints were implemented when randomizing the order of trials. First, the same type of question (nominal, ordinal, interval, and ratio) could not be asked consecutively. Second, the same types of display (text and graph) within a trial were always shown together. Third, the same lipid value (cholesterol, LDL, HDL, triglyceride) could not be asked consecutively.

Numbers of Groups and Subgroups

The experiment was of a within-subject design with two independent variables. Each subject completed all the questions. There were following variables considered in this study.

- Independent variable one: question type
    - It had one level in Part I, which was the nominal display.
    - It had four levels in Part II, which were the nominal, ordinal, interval, and ratio displays.
    - It had one level in Part III, which was the nominal display.
    - It had four levels in Part IV, which were the nominal, ordinal, interval, and ratio displays.
- Independent variable two: representation
    - It had three levels in Part I, which were the nominal display, ordinal display, and ratio display.
    - It had two levels in Part II, which were the text and graph displays.
    - The dependent measures were response time and the correctness of answer.

- There were two between-subject factors which were planned to be analyzed. The assumption was that there were no significant differences between the factors. The two factors were:
    - Professional background: healthcare background or non-healthcare background; and
    - Gender: male or female.

Numbers of Questions in Each Group

- *Part I*, a one-dimensional search on nominal questions represented by nominal, ordinal, and ratio displays, included 3 trials. Each trial contained 6 questions, totaling 18 questions.
- *Part II*, a one-dimensional search on nominal, ordinal, interval and ratio questions represented by table and graph displays, included 6 trials. Each trial contained 8 questions, with a total of 48 questions.
- *Part III*, a two-dimensional search on nominal questions represented by nominal, ordinal, and ratio displays, included 3 trials. Each trial contained 6 questions, totaling 18 questions.
- *Part IV*, a two-dimensional search on nominal, ordinal, interval and ratio questions represented by table and graph displays, included 6 trials. Each trial contained 8 questions, for a total of 48 questions.
- There were a total of 132 questions for each subject.

Setting

The experiments were conducted in a private cubicle within the Cognitive Informatics Laboratory located at the School of Health Information Sciences, University of Texas Health Science Center at Houston.

All experiment materials were presented to the subjects using an IBM-A31 laptop computer with an identical screen resolution. An external mechanical mouse was connected to the computer.

All subjects claimed themselves to be right-handed, so the mouse was not adjusted for left-handed usage.

PROCEDURE

Recruited subjects were required to read the IRB approved consent form, in which the purpose, potential risks, benefits, and the amount of compensation were indicated. The primary investigator addressed the subjects' concerns and questions about the experiment. When there were no further questions, the subjects signed the consent forms.

All subject information was then coded using a study accession number. There was no direct identifiable link between the data collected and the subjects.

Subjects started with the training session, in which they were presented with the normal lipid panel range chart, exercise questions on those normal ranges for memorizing purposes, and sample test questions were presented. They were told to take a break during the training session and instructed to complete all tasks as quickly and accurately as possible. Response time and answers to each question were automatically recorded in the Excel sheets.

All questions related to the training session were answered by the primary investigator prior to the start of the experiment. Subjects were informed that it was allowable to take a break between trials and between experiments. The response time recorded was merely for the period required for each task, before clicking the “submit” button. Subjects could not return to the previous task once the “submit” button had been clicked.

On average, each subject took less than 45 minutes, including breaks, to complete the entire experiment. Each subject was given a 10-dollar grocery gift card as compensation for his/her participation in this research. No subjects withdrew from this research.

SUMMARY

This chapter describes the experiments I designed to test the three hypotheses, in accordance with the theoretical analyses. Hypothetical lipid panels representing relational data were used for the empirical studies. Variables corresponding to the hypotheses were identified and described. Sample sizes were statistically planned and the experimental setting was controlled appropriately.

CHAPTER V

DATA COLLECTION AND ANALYSIS

This chapter depicts issues related to the collection of data, and experimental procedure, and presents the statistical considerations. The experiments were conducted in 2006. All hypotheses were tested through the within-subject design described in Chapter IV.

DATA COLLECTION AND ANALYSIS

Data from each participant were collected using the following method. All data were originally collected and stored in the Excel sheet associated with each trial. Data were then transferred and combined into a single Excel sheet including response time and the correctness of each questions. A total of 3168 data points were obtained through the experiments.

Data were then clustered for experiment, and sorted by question type and display. Wrong answers were color-coded in red. A total of 135 wrong answers were found and then excluded from further data analyses.

Outliers for each question represented by the same display were calculated and eliminated from further analysis. Outlier calculation was conducted using the following procedure (Hoaglin *et al.*, 1983):

1. Order the values and note the DEPTH of each (the rank from the nearest extreme value).

DEPTH 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

VALUE 32 47 53 59 77 77 81 90 96 118 120 120 131 135 143 151 162 174 187 189 195 205 210 220 248 281 300 309 337 475

2. Find the DEPTH of the median as: (N + 1) / 2 = 31 / 2 = 15.5.
3. Find the DEPTH of the fourths (similar to quartiles) as: (median depth + 1)/2 = (15 + 1)/2 = 16/2 = 8.

NOTE: When computing fourths, always drop any fractional part of the depth of the median before adding the 1. In this case, the calculated median depth was 15.5. The fraction is dropped, changing the median depth to 15, which is then entered into the formula.

4. Find the VALUES of the fourths: the lower fourth has a value at depth of 8 is 90; the upper fourth is 210.
5. Find the FOURTH SPREAD as the difference between the values of the 1st and 3rd fourths: 210 - 90 = 120.
6. An outlier is defined as any score which is more than 1 ½ fourth spreads beyond either fourth. If the data were normally distributed, about 7/1000 cases would be identified as outliers.

Lower outlier bound is = lower fourth value - 1.5 (fourth spread) = 90 - 1.5 (210 - 90) = -90 (no "too small" outliers).

Upper outlier bound is = upper fourth value + 1.5 (fourth spread) = 210 + 1.5 (210 - 90) = 390 (475 is an outlier).

Employing Hoaglin's method, I eliminated the following outliers and incorrect answers of each subject (see Table 22). Table 23 presents the total number of outliers and incorrect answers for each part. Table 24 presents the total number of outliers and incorrect answers for each question.

Table 22. The Total Number of Incorrect Answers and Outliers for Nominal Questions on Nominal, Ordinal, and Ratio Displays

	Incorrect Answers			Outliers			Incorrect Answers			Outliers		
Sub#	1DN	1DO	1DR	1DN	1DO	1DR	2DN	2DO	2DR	2DN	2DO	2DR
1												
2										1	2	1
3	1	3	2	1	1	3		1	2	1		1
4									1	1		
5					1					1		1
6				1						1		
7			1						1			2
8		2			1							
9		1										
10			3			1		1	3			1
11		1		1	2				1			1
12			5						5	1	1	
13			3	1					2			
14		1										1
15			1			4	1					
16							2	2	1			1
17		1										
18		1	2				1		3			
19					2	2				1	2	
20					1							2
21			1		1	1			1	1		1
22									1			
23	1		1	1	1							1
24							1					
Total	2	10	19	5	10	11	5	4	22	8	5	13
Ttl		31			26			32			26	

Abbreviations: 1D: 1-dimension; 2D: 2-dimension; N: Nominal; O: Ordinal; R: Ratio

Table 23. Outlier Values and the Total Number of Outliers Eliminated for Each Part

1DTG				
	q3	q1	calculation	# outlier
Gi	12.36	7.7	19.35	6
Gn	9.54	6.4	14.25	6
Go	10.91	6.62	17.35	10
Gr	16.27	9.32	26.70	7
Ti	15.19	9.57	23.62	2
Tn	9.63	6.62	14.15	4
To	12.69	8.59	18.84	8
Tr	19.08	10.17	32.45	9
2DTG				
	q3	q1	calculation	# outlier
Gi	10.58	6.89	15.77	7
Gn	9.91	6.58	14.91	10
Go	9.63	5.93	15.18	8
Gr	13.44	7.44	22.44	7
Ti	12.51	7.54	19.97	14
Tn	9.03	5.83	13.83	7
To	9.89	6.59	14.84	10
Tr	15.37	8.41	25.81	6
1DNOR				
	q3	q1	calculation	# outlier
N	10.19	6.87	15.17	5
O	11.93	7.7	18.28	10
R	14.13	8.64	22.37	11
2DNOR				
	q3	q1	calculation	# outlier
N	15.1	8.92	24.37	8
O	13.48	8.4	21.1	5
R	32.9	19.66	52.76	13

A total of 2860 data points were collected and prepared for further statistical analysis. During the preparation, a total of 173 outlier data were eliminated from further statistical analysis. A total of 135 incorrect answers were also eliminated from further statistical analysis.

Table 24. The Total Number of Incorrect Answers and Outliers for the Table and the Graph Displays

	1 Dimension Incorrect Answers								1 Dimension Outliers								2 Dimension Incorrect Answers								2 Dimension Outliers							
Sub#	Gi	Gn	Go	Gr	Ti	Tn	To	Tr	Gi	Gn	Go	Gr	Ti	Tn	To	Tr	Gi	Gn	Go	Gr	Ti	Tn	To	Tr	Gi	Gn	Go	Gr	Ti	Tn	To	Tr
1										1					1									1				1	1	1		1
2							1		1	2	1	2	1	1											2	1	1	1	1	1		
3			2		1			1		1					1	2								1					1		1	
4					1	1					1												1	1		1	1		1			
5								1							1	3											1		1		3	
6					1																											1
7								1	1							1													2		1	
8			1				1								1		1							1				1		1		
9																																
10			2		1	1	1													1								1	1			
11				1			2																									
12		1							1			1		1		1											1					
13						1			1	1																						
14		2					1				1														1	1			1		1	1
15				1				1		1																			1		1	1
16			3		1			1	1						2		1			2				2					1			
17				1			1	3			1	1												1							1	
18				2	2	1	1	2			3	2					1			1	1				1	1		1			1	1
19											1				1	1										2				1		
20																														1	1	
21		1									1					1			1							1			1	1		
22			1		1		1								1								1	1	1		1	1	2			1
23			1			1	1		1		1	1	1	2			1								2	3	3	1		1		
24																																
Tl	0	4	10	5	8	5	10	10	6	6	10	7	2	4	8	9	4	0	1	4	1	0	2	8	7	10	8	7	14	7	10	6
Ttl		19				33				29				23				9				11				32				37		
Tttl				52								52								20								69				

STATISTICAL CONSIDERATIONS

The primary purpose of these experiments was to verify the relational data search model that I proposed in Chapter VI. The response time on different tasks for each display was of interest. The within-subject designs have to reach the power. A Java applet was employed in this study for power and sample size calculation (Lenth, 2006).

There were basically two experimental designs.

Design 1: The purpose of this design was to examine the effects of nominal questions on different data scale displays. The 3 x 1 table shown in Table 25 depicts the repeated measure design for Part I and III, which tested one-dimensional and two dimensional searches. An analysis of variance (ANOVA) was used to test for statistical significance using the General Linear Model within SPSS. If using 12 subjects, the power is 0.9912. Figure 13 depicts the power calculation result from design 1.

Table 25. ANOVA Design for Parts I and III

	Nominal Question
Nominal Display	Time/Correctness
Ordinal Display	Time/Correctness
Ratio Displayg	Time/Correctness

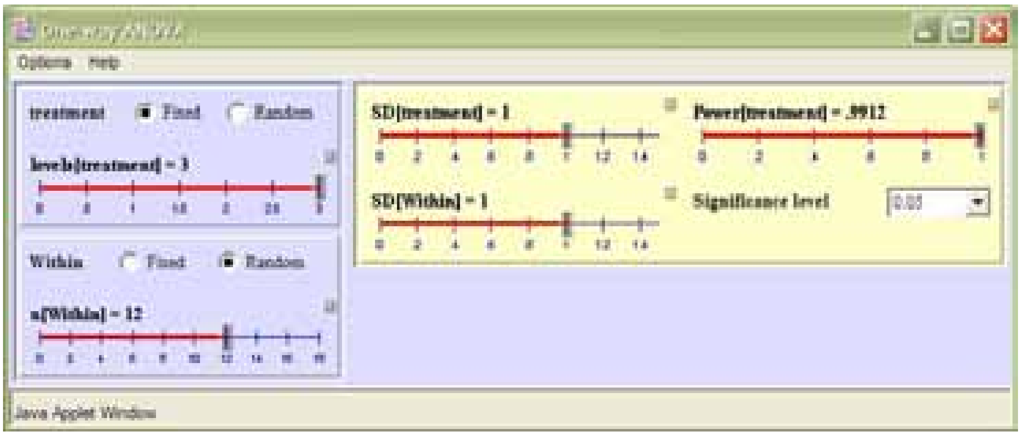


Figure 13. The power calculation for one-way ANOVA design of Parts I and III

Design 2: This design was to examine the effects of text and graph displays on question types (nominal, ordinal, interval, and ratio). The 4 x 2 table shown in Table 26 depicts the repeated measure design for Part II and IV, which tested one-dimensional and two-dimensional searches. An ANOVA was used to test for statistical significance using the General Linear Model within SPSS. If using 12 subjects, the power is 0.9995. Figure 14 depicts the power calculation result of Design 2.

Table 26. ANOVA Design for Parts II and IV

	Nominal	Ordinal	Interval	Ratio
Text	Time/Correctness	Time/Correctness	Time/Correctness	Time/Correctness
Graph	Time/Correctness	Time/Correctness	Time/Correctness	Time/Correctness

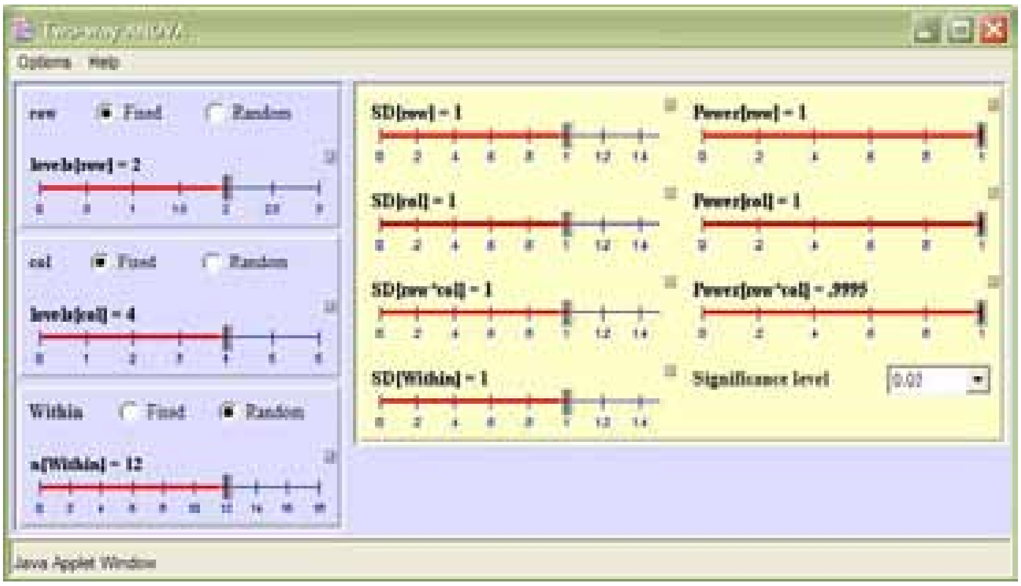


Figure 14. The power calculation for one-way ANOVA design of Parts I and III

Besides ANOVA method deployed as a main approach in this study, I also used other analysis methods such as paired T Test, Correlation for examining some interesting phenomena.

ANALYSIS OF DATA

The purpose of this study was to validate the model and to determine the degree of difference of search performance among tasks. Three hypotheses were evaluated through four parts. Each participant completed all four parts.

This study solicited a purposeful sample of 24 subjects from the graduate schools within the Texas Medical Center. The sample was comprised of 12 healthcare background students and 12 non-healthcare background students. Healthcare backgrounds include registered nurses, physicians, and medical technicians, etc. Of the 24 subjects, 12 were male and 12 were female.

SUMMARY

As planned, the data collection procedure was strictly followed. Data was successfully collected and transformed into usable format for using SPSS statistical software. Statistical considerations were given to the power calculations of ANOVA designs. In order to counter-balance the carry-on effect brought by within-subject design and to achieve statistical power, the minimum sample size was 12. Two interesting between-group factors, gender and occupation, were also included in the design. A total of 24 appropriate subjects were recruited.

CHAPTER VI

RESULTS AND DISCUSSION

This chapter describes the statistical results and discusses the results corresponding to each research hypothesis.

STATISTICAL ANALYSIS RESULTS

Part I – 1D Nominal Task with Nominal, Ordinal, and Ratio Displays

In Part I, searching one-dimensional nominal tasks on nominal, ordinal and ratio displays, a repeated measure ANOVA revealed a statistically significant difference in response time among nominal, ordinal and ration displays. The average response time for the tasks performed in nominal display was 8.60 ± 1.25 seconds. The average response time for the tasks performed in ordinal display was 9.90 ± 1.70 seconds. The average response time for the tasks performed in ratio display was 11.20 ± 2.11 seconds. As expected, there was a main effect of display type (nominal, ordinal, ratio), $F(2,40)=30.28$, $p<.001$. The numbers or incorrect answers were 2, 10, and 19 for nominal, ordinal and ratio displays, respectively (Figure 16). There were no effects due to professional or gender. No significant two-way interactions between display and professional background, or display and gender were found.

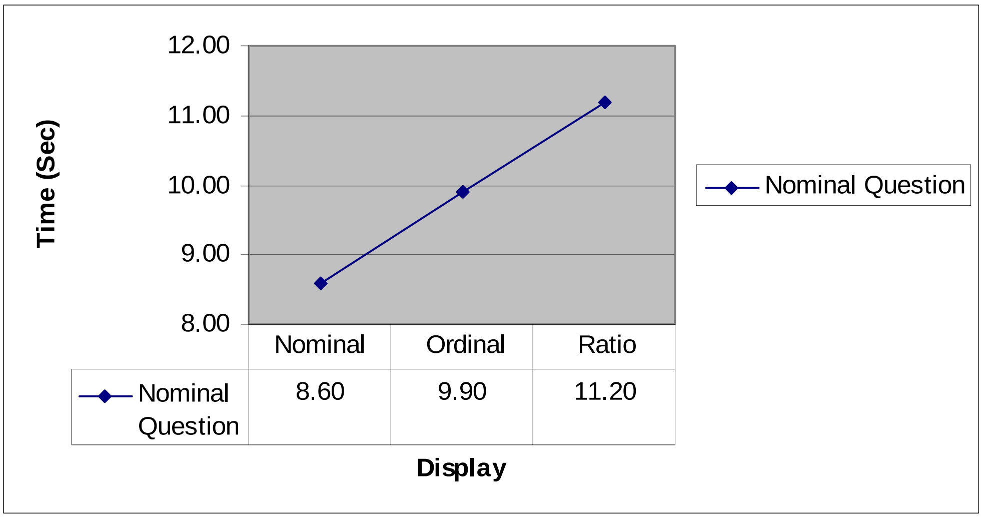


Figure 15. The response time of nominal questions on the nominal, ordinal and ratio displays – one dimension

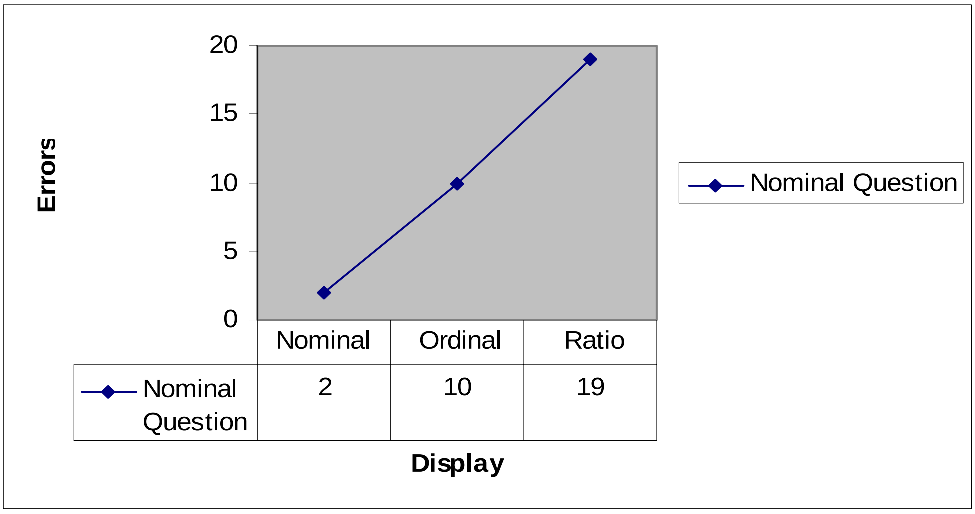


Figure 16. The number of error answers of nominal questions searched on the nominal, ordinal, and ratio displays – one dimension

Part II – 1D Nominal, Ordinal, Interval and Ratio Tasks with

Graph and Table Displays

In Part II, searching nominal, ordinal, interval and ratio tasks on graph and table displays, a repeated measure ANOVA revealed a statistically significant difference in response time among nominal, ordinal and ratio tasks on graph and table displays.

The average response time for the nominal tasks performed in graph display was 7.95±1.31 seconds. The average response time for the ordinal tasks performed in graph display was 8.70±2.05 seconds. The average response time for the interval tasks performed in graph display was 9.90±2.45 seconds. The average response time for the ratio tasks performed in graph display was 12.90±3.02 seconds.

The average response time for the nominal tasks performed in table display was 8.20±1.51 seconds. The average response time for the ordinal tasks performed in table display was 10.56±2.11 seconds. The average response time for the interval tasks performed in table display was 12.53±2.82 seconds. The average response time for the ratio tasks performed in table display was 14.56±3.53 seconds.

As expected, there was a main effect of question type (nominal, ordinal, interval and ratio), $F(1,21)=28.69$, $p<.001$.

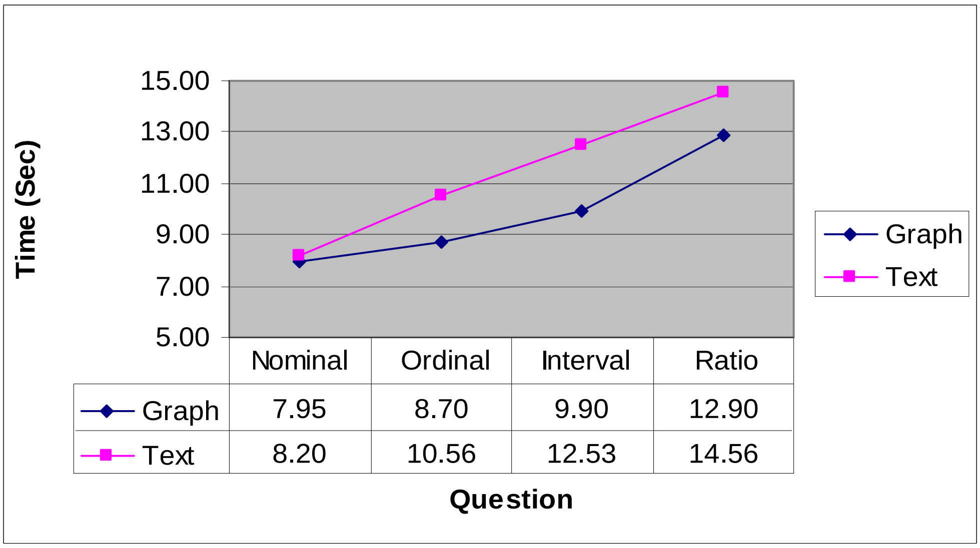


Figure 17. The response time of the nominal, ordinal, interval and ratio questions searched on graph and text displays respectively – one dimension

Paired T-Test

A paired-test was performed to examine the main effect between graph displays and table displays at each level as well as the difference between different questions types on each display. Except the pair Gn (Graph nominal) – Tn (Table nominal), P=.237 does not show a significant effect. All other pairs indicate significant differences at the .05 level. The results are shown in Table 27.

Table 27. Paired Samples Test for One-dimension Search

	df=23	Sig. (2-tailed)
Pair 1	Gn - Tn	.237
Pair 2	Go - To	.000
Pair 3	Gi - Ti	.000
Pair 4	Gr - Tr	.024
Pair 5	Gn - Go	.028
Pair 6	Gn - Gi	.000
Pair 7	Gn - Gr	.000
Pair 8	Go - Gi	.000

Pair 9	Go - Gr	.000
Pair 10	Gi - Gr	.000
Pair 11	Tn - To	.000
Pair 12	Tn - Ti	.000
Pair 13	Tn - Tr	.000
Pair 14	To - Ti	.000
Pair 15	Ti - Tr	.008

Part III – 2D Nominal Task with Nominal, Ordinal, and Ratio Displays

In Part III, searching two-dimensional nominal tasks on nominal, ordinal, and ratio displays, a repeated measure ANOVA revealed a statistically significant difference in response time among nominal, ordinal and ratio displays.

The average response time for the tasks performed in nominal display was 12.03±2.94 seconds. The average response time for the tasks performed in ordinal display was 10.92±1.95 seconds. The average response time for the tasks performed in ratio display was 26.04±6.40 seconds. As expected, there was a significant effect due to display type (nominal, ordinal, ratio), $F(2,40)=141.36$, $p<.001$. The numbers or incorrect answers were 2, 10, and 19 for nominal, ordinal and ratio displays respectively (Figure 19). There were no effects due to professional and gender. No significant two-way interactions between display and professional background, or display and gender were found.

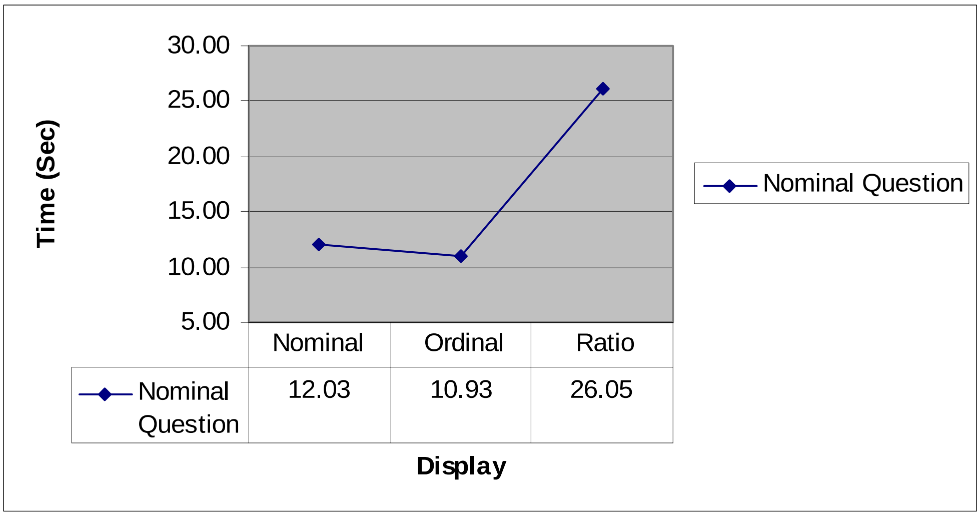


Figure 18. The response time of nominal questions on the nominal, ordinal and ratio displays – two dimensions

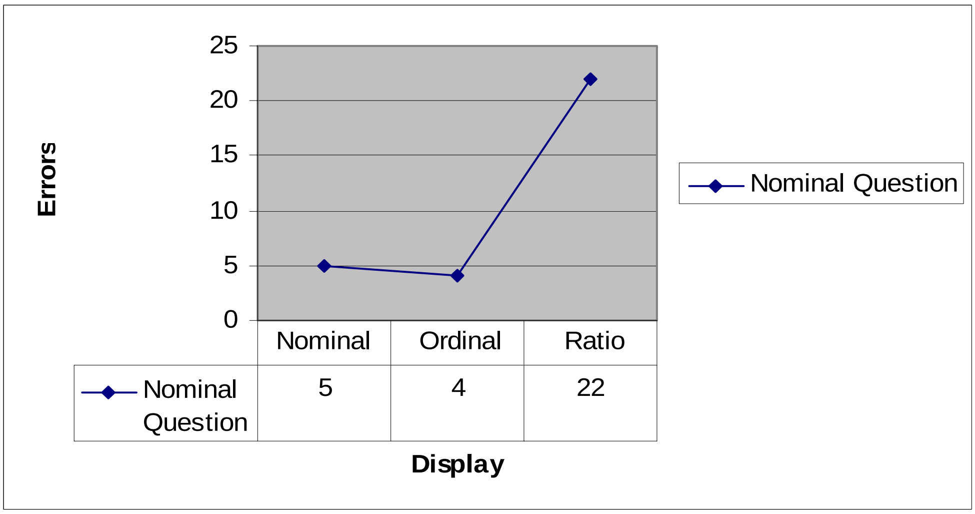


Figure 19. The number of error answers of nominal questions searched on the nominal, ordinal and ratio displays – two dimensions

Part IV- 2D Nominal, Ordinal, Interval, and Ratio Tasks with Graph and Table Displays

In Part IV, searching two-dimensional nominal, ordinal, interval and ratio tasks on graph and table displays, a repeated measure ANOVA revealed a statistically significant difference in response time among nominal, ordinal and ratio tasks on graph and table displays.

The average response time for the nominal tasks performed in graph display was 8.32 ± 1.80 seconds. The average response time for the ordinal tasks performed in graph display was 7.75 ± 1.74 seconds. The average response time for the interval tasks performed in graph display was 8.76 ± 1.91 seconds. The average response time for the ratio tasks performed in graph display was 10.55 ± 2.70 seconds.

The average response time for the nominal tasks performed in table display was 7.45 ± 1.50 seconds. The average response time for the ordinal tasks performed in table display was 8.23 ± 1.35 seconds. The average response time for the interval tasks performed in table display was 9.89 ± 1.72 seconds. The average response time for the ratio tasks performed in table display was 11.64 ± 2.86 seconds.

As expected, there was a large effect due to question type (nominal, ordinal, interval and ratio), $F(1,21)=24.22$, $p<.001$. (See Figure 20)

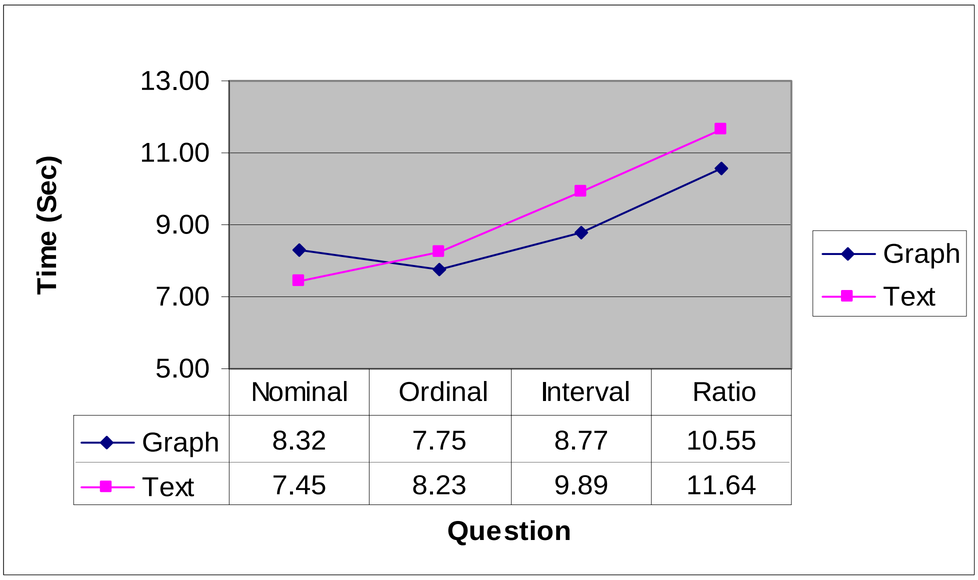


Figure 20. The response time of the nominal, ordinal, interval and ratio questions searched on graph and text displays– two dimensions

Paired T-Test

A paired-test was performed to examine the main effect between graph displays and table displays at each level as well as the difference among questions types on each display. Except the pair Go (Graph nominal) – To (Table nominal), P=.070 does not show a significant effect. All other pairs indicate significant differences at the .05 level. However, for the pair Gn – Tn, the response time for Gn is significantly greater than Tn (see Table 28)

Table 28. Paired Samples Test for Two-dimension Search

df=23		Sig. (2-tailed)
Pair 1	Gn - Tn	.003
Pair 2	Go - To	.070
Pair 3	Gi - Ti	.005
Pair 4	Gr - Tr	.026
Pair 5	Gn - Go	.017
Pair 6	Gn - Gi	.046

Pair 7	Gn - Gr	.000
Pair 8	Go - Gi	.000
Pair 9	Go - Gr	.000
Pair 10	Gi - Gr	.000
Pair 11	Tn - To	.019
Pair 12	Tn - Ti	.000
Pair 13	Tn - Tr	.000
Pair 14	To - Ti	.000
Pair 15	Ti - Tr	.000

Comparing One Dimensional and Two-Dimensional Searches for Nominal Tasks

A paired-test was performed to examine the mean difference between one-dimensional and two-dimensional searches for nominal tasks. (Pair 1 Nominal one dimension (N1) – Nominal two dimension (N2), T (23) =-.6.779, P<.05; Pair 2 O1 – O2, T (23) =-.2.245, P<.05; Pair 3 R1 – R2, T (23) =-11.448, P<.05). All pairs have significant difference at the .05 level.

I performed statistical analyses on graph displays and table displays at each level. I examined difference between all questions types on each display. Except for the pair Go (Graph nominal) – To (Table nominal), P=.070, it does not show a significant effect. All other pairs indicate significant differences at .05. However, for the pair Gn (Graph nominal) – Tn (Table nominal), the response time for Gn is significantly greater than that of Tn.

The Figure 21, Figure 22, and Figure 23 indicate the total number of incorrect answers for both healthcare and non-healthcare participants; the answers are subcategorized by type of question. There were no statistical differences between the two groups.

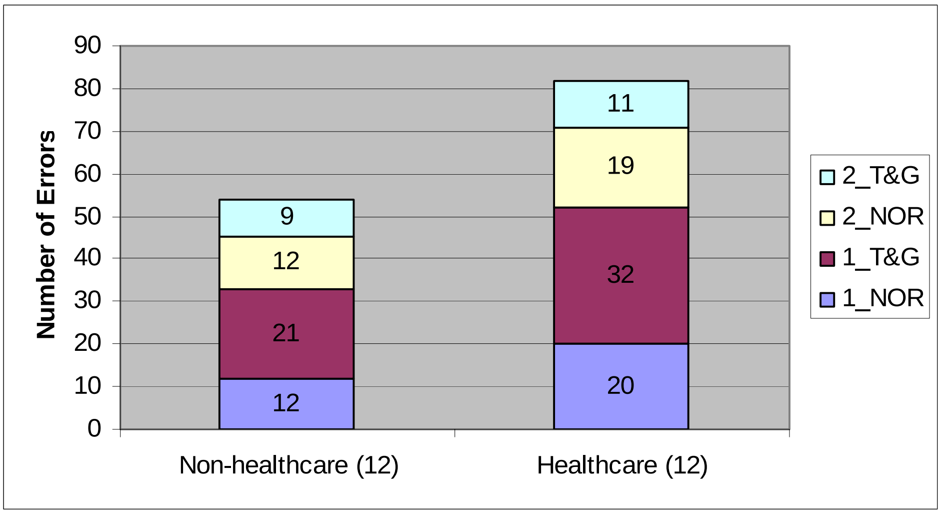


Figure 21. A comparison of incorrect answers between healthcare and non-healthcare participants

T&G: Table and graph displays for all tasks;

NOR: Nominal tasks searched on nominal, ordinal and ratio displays

1: one dimension; 2: two dimension

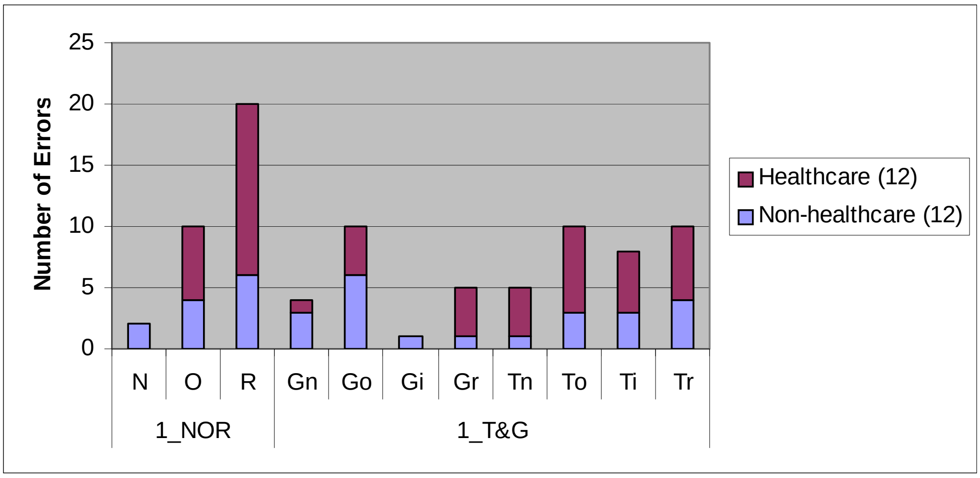


Figure 22. Incorrect answers in one-dimensional searches made by healthcare and non-healthcare participants

N: Nominal displays

O: Ordinal displays

R: Ratio displays

Gn: Graph displays with nominal questions

Go: Graph displays with ordinal questions

Gi: Graph displays with interval questions

Gr: Graph displays with ratio questions

Tn: Table displays with nominal questions

To: Table displays with ordinal questions

Ti: Table displays with interval questions

Tr: Table displays with ratio questions

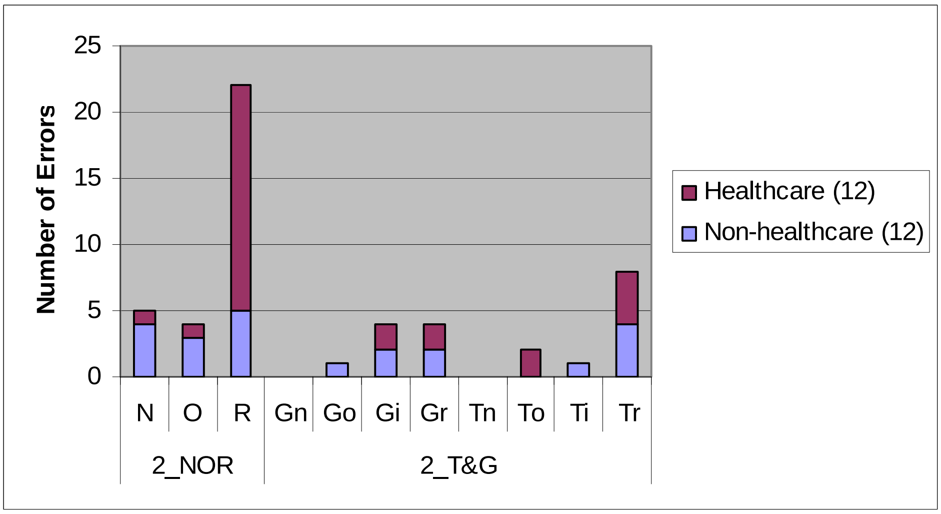


Figure 23. Incorrect answers in two-dimensional searches made by healthcare and non-healthcare participants

N: Nominal displays

O: Ordinal displays

R: Ratio displays

Gn: Graph displays with nominal questions

Go: Graph displays with ordinal questions

Gi: Graph displays with interval questions

Gr: Graph displays with ratio questions

Tn: Table displays with nominal questions

To: Table displays with ordinal questions

Ti: Table displays with interval questions

Tr: Table displays with ratio questions

Correlation

Pearson Correlation analysis was carried out on response time (time) and number of error answers (error). In one dimension, see Figure 24, there was a significant correlation at the .05 level R=.999 $P<.05$, which indicates a nearly perfect positive relationship between response time and number of error answers. In two dimensions, see Figure 25, there is a significant correlation at the .05 level R=1.000 $P<.05$, which indicates a perfect positive relationship between response time and number of error answers.

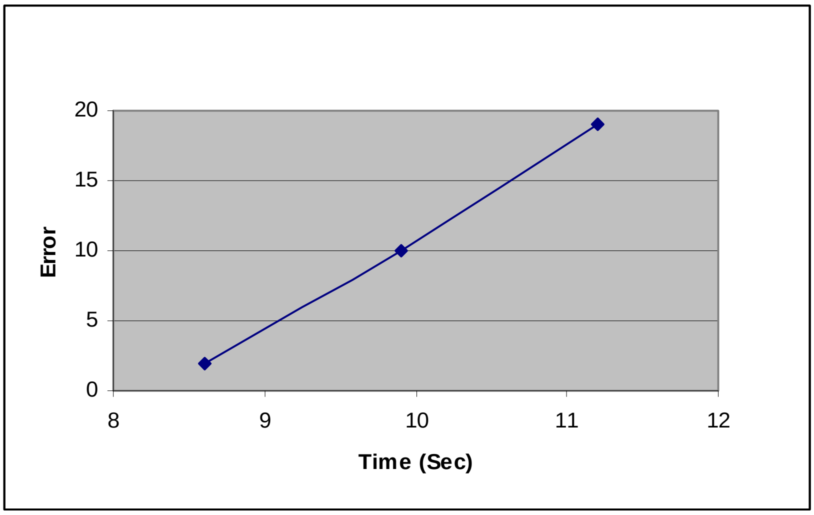


Figure 24. Speed and accuracy tradeoff of one-dimensional Search

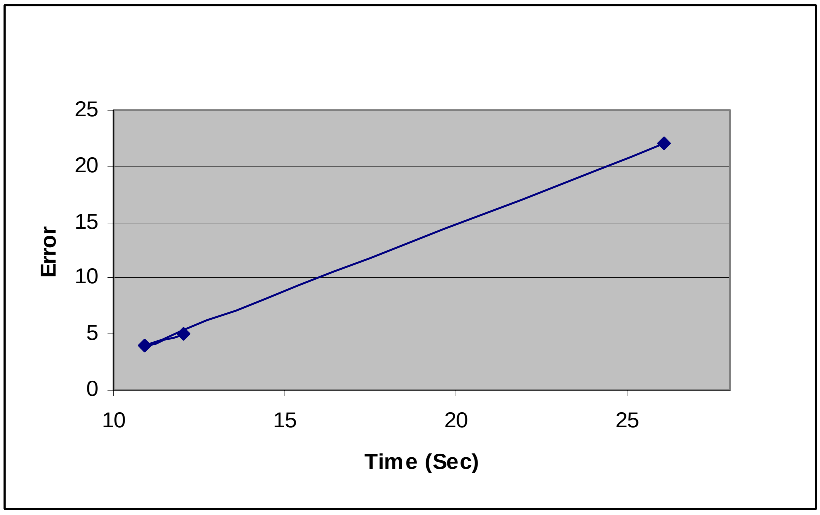


Figure 25. Speed and accuracy tradeoff of two-dimensional Search

DISCUSSION

The three hypotheses in this study are generally supported by the experiments.

Hypothesis I

It was hypothesized that information search with more external information yields a better task performance than that with less external information. In this study, the Experiments III and IV indicate, in general, that graph displays for all types of search tasks lead to superior performance. However, in the one-dimensional search, nominal search tasks do not show significant differences between graph and table displays. Even in the two-dimensional tasks, the table display is significantly better than the graph's (P=.003).

Theoretically, the information represented in external representations can be picked up by perceptual processes, whereas the information in internal representations has to be retrieved from memory. The abnormality of the performance discovered in searching the nominal questions on table displays could be explained as people not being at the same level of familiarity in terms of graph and table. Typically, in everyday's routine tasks, nominal tasks are represented in tables. Though the training session was helpful in preparing the participants to reach the same cognitive level, some participants still had better recognitions with table displays.

Hypothesis II

It was hypothesized that an exact representations between task and data representation yields a better performance than an over-representations. This hypothesis is supported by Part I, the one-dimensional search, which shows an increasing trend in terms of response time and error rate. When a nominal question is searched for in a nominal display, the response time is significantly faster than the response time performed in ordinal and ratio displays. However, this hypothesis is not supported by Part III. This is probably because a two-dimensional search is a more complex task and involves a lot of non-ordinal elements (date) and non-ratio elements in the tasks which might have interfered with the effect.

Hypothesis III

Hypothesis III: Two-dimensional searches are error-prone and more complex than one-dimensional searches. This is partially supported by the comparison between the one-dimensional search of nominal task (Part I) and the two-dimensional search of nominal task (Part II). The paired T test shows that the one-dimensional search has a much shorter response time than the two-dimensional search. However, there is no statistically significant difference between the numbers of errors in the two experiments.

This research study is a within-subject experimental design, and compares the performances of each person with different information representations. There are no statistical differences of response time and error rate due to gender or professional background.

SUMMARY

The response time and accuracy of nominal search tasks were statistically analyzed in this chapter. Two between-group factors, gender and occupation (healthcare or non-healthcare), were also considered. The response time and number of errors showed positive correlations for both one-dimensional and two-dimensional searches. My hypotheses were generally supported by my statistical results.

CHAPTER VII

SUMMARY AND CONCLUSION

The results of my analyses show that task analysis reveals the steps that need to be performed to reach a goal. For each step in a search task, the information needed to carry out the step can be either internal or external information. According to my analyses, the steps and the information required for each step dependent on the interface for a search task jointly determine the efficiency, task complexity, and the possibility of making errors.

The experimental results generally support my hypotheses and match my analysis results.

IMPLICATIONS FOR HEALTH INFORMATICS

This research on internal and external information in information search has both theoretical and practical implications. It reveals how the human information seeker interacts with artifacts in information search tasks conducted under different distributed conditions. The framework of a distributed information search and the search task taxonomy constitute a theoretical contribution to the study of information search and distributed cognition, and to the disciplines of human-centered computing. The practical contribution is the effective prediction and better design of search interfaces when considering data scale and the distributed nature of information.

For the healthcare industry, this study provides evidence for an effective design/redesign of a medical device which is typically used by patients, nurses, physicians and technicians. The search task taxonomy depicts the different natures of tasks at an abstract level. This is applicable to the analysis of the information search task of relational data. The search performances over the displays can be used as a guideline suitable for search interfaces of relational data.

CONCLUSIONS

It can be thus concluded from my research that *UFuRT* is applicable to the design and evaluation of usability of interfaces for information search. It is a useful process that can not only provide design guidelines but also generate estimates of representational efficiencies, task complexities and user behavioral outcomes.

The relational data search model and taxonomy are good for designing effective search interfaces. The model predicts the search performance especially well in one-dimensional searches.

In healthcare practice, physicians, nurses and other users spend a large amount of time reading and searching for healthcare data in medical records. Exhaustive displays of laboratory results can easily overwhelm their ability to comprehend and explain the data, making the decision-making process error-prone.

Prototypes of distributed information search tools based on human-centered computing and distributed cognition, such as that presented here, are applicable in information search tool design of an EHR that supports, facilitates, and enhances healthcare practice.

LIMITATIONS

This study analyzed the one-dimensional and two-dimensional search tasks for relational data and selectively implemented the search interfaces with the proper search tasks. For example, the study examined the effect of the nominal search task in nominal, ordinal and ratio displays; however, the ordinal search task was not examined in ordinal and ratio displays.

In my studies, the hypothetical lipid panel results were employed as examples to test and verify the theoretical framework and search models for relational data. The lipid panel as a representative for relational data is generalizable to other relational data, yet the inter-relationship among the variables such as total cholesterol, HDL, LDL, and so on, is unique, and therefore may not be generalizable to other relational data.

Other relational data typically presented in a patient's chart, such as temperature, weight, blood pressure, etc. may construct other relationships for search tasks; accordingly, the search tasks may possess some nature other than this lipid panel. Thus, a careful consideration is needed for other special relational data.

Search performance over time on the relational data was not included in this study due to the fact that the search tasks performed in this study were designed for novice users of a medical record system. It would be interesting to examine the search effect as the novice users gain experience.

FUTURE DIRECTIONS

Upon comparison, the experiment results for the two-dimensional searches did not match the theoretical analysis as much as the one-dimensional searches did. The two-dimensional searches were more complex than the one-dimensional ones. There might be other factors that should be included in experimental design. For example, it would be an interesting phenomenon to observe searching a hybrid representation, such as a search when one of the two-dimensional data would be represented on a less powerful scale and another would be represented on a more powerful scale.

More experiments are also needed to further explain why the nominal tasks on the table displays have a better response time than those on graph displays. These interests also extend to non-relational data search tasks.

The full set of search tasks coupled with the same or higher level representations is expected. Additional experiments on ordinal tasks are needed to test the search performance of ordinal, interval, and ratio displays. Further work is needed to conduct additional experiments on interval tasks to test the search performance of interval and ratio displays and to use the ordinal displays to test ordinal and ratio search tasks.

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APPENDIX A: CPHS APPROVAL

THE UNIVERSITY *of* TEXAS
HEALTH SCIENCE CENTER AT HOUSTON

THE COMMITTEE *for the* PROTECTION *of* HUMAN SUBJECTS

7000 Fannin, Suite 750
PO Box 20036
Houston, TX. 77225

713 500 3985
713 500 0319 fax

Jiejie Zhang, PhD
The University of Texas Health Science Center at Brownsville
School of Health Information Sciences

NOTICE OF APPROVAL TO BEGIN RESEARCH December 3, 2004

HSC-SHIS-04-008 – "The Interaction Between Internal and External Information in Information Searching"
PI :Jiejie Zhang, PhD; et al

PROVISIONS: This approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered by the Committee for the Protection of Human Subjects, e.g. study documents, informed consents, etc. For personnel who have not submitted proof this required education, education proof is required or we cannot approve these individuals to work with any human subjects or human derived data involved in this study. Student Information Form provided in English should be translated and submitted for approval prior to administering survey to Spanish speaking students.

APPROVED: By Expedited Review and Approval

APPROVAL DATE: December 3, 2004 **EXPIRATION DATE:** November 30, 2005

CHAIRPERSON: Anne H. Dougherty, MD

Subject to any provisions noted above, you may now begin this research.

CHANGES: The principal investigator (PI) must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.

INFORMED CONSENT: When Informed consent is required, it must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. **Please note that only copies of the stamped approved informed consent form can be used when obtaining consent.**

HEALTH INSURANCE PORTABILITY and ACCOUNTABILITY ACT (HIPAA):
The study must meet all HIPAA research requirements. For compliance guidelines see details on the Committee for the Protection of Human Subjects website at:
http://www.uth.tmc.edu/ut_general/research_acad_aff/orsc/cphs/guidelines/hipaa.htm

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent and HIPAA documents if required, in a manner that ensures subject confidentiality.

APPENDIX B: SUBJECT RECRUITMENT LETTER

Recruitment Letter

Research participants are needed for an information experiment conducted by Dr. Jiajie Zhang at School of Health Information Sciences, The University of Texas – Health Science Center at Houston. The title of the study is "The Interaction between Internal and External Information in Information Searching" (HSC-SHIS-04-008). The purpose of the research is to study how people search different types of interface of medical record for different types of question. The experiment will last approximately one hour, and participants will be compensated for their time of participating.

People with all backgrounds, including women and minorities, are encouraged to participate. Your participation in this research is voluntary. Should you decide to participate, you may withdraw at any time without penalty. Your contribution to the research project will be kept confidential.

The first 108 people responding to the ad will be selected. For further information, please contact the person listed below, by phone or by email.

Yang Gong, Ph. D. Candidate

Phone: 713 500-3639 Email: Yang.Gong@uth.tmc.edu

School of Health Information Sciences
The University of Texas – Health Science Center at Houston
7000 Fannin Street, Suite 600
Houston, Texas 77030

This study (HSC-SHIS-04-008) has been reviewed by the Committee for the Protection of Human Subjects (CPHS) of the University of Texas Health Science Center at Houston. For any questions about research subject's rights, or to report a research-related injury, call the CPHS at (713) 500-3985.

APPENDIX C: CONSENT FORM

The Interaction between Internal and External Information in Information Searching

CPHS HSC #: HSC-SHIS-04-008
Principal Investigator: Jiajie Zhang, Ph.D.

Consent to Participate in Experiments

You are invited by Dr. Jiajie Zhang to take part in a study about information search on computer interface of medical record. Before you take part, your decision to take part is voluntary and you may refuse to take part, or choose to stop taking part, at any time. A decision not to take part or to stop being a part of the research project will not result in any penalties. You may refuse to answer any questions asked or written in any forms. This research project has been reviewed by the Committee for the Protection of Human Subjects (CPHS) of the University of Texas Health Science Center at Houston as HSC-SHIS-04-008.

The purpose of this experiment is to study how people search information through different interfaces and different types of search questions. The experiment will typically last approximately one hour.

Taking part in this study you will also be asked to read the question first and then search the data displayed in a certain format on a computer screen. These questions involve estimating efficiency of interface design for Electronic Medical Record. This is not a test of your knowledge or capabilities. Rather, it is intended solely for research purposes.

If you should agree to take part, you will be noted that your time spending on answering each question will be recorded. You may receive no direct benefit from being in this study; however, your taking part may help provide better design the medical record in future.

Your taking part in this experiment only involves answering questions displayed on a computer screen. The risks of harm anticipated are not greater, considering probability and magnitude, than those ordinarily encountered in daily life or during the performance of routine physical of psychological examinations or tests. You understand that you can withdraw the experiment at any time for any reason.

You will not be personally identified in any reports or publications that may result from this study. Any personal information about you that is gathered during this study will remain confidential to every extent of the law. A special number will be used to identify you in the study and only the investigator will know your name.

You understand that you will receive $10/hour or partial hour for your taking part in this experiment. You further understand that you may elect to withdraw from the study at any time for any reason and still receive payment for the time you have spent in the study.

If you have further questions regarding this project, you may contact the principal investigator at any time: Dr. Zhang at 713-500-3922.

Sign below only if you understand the information given to you about the research and choose to take part. Make sure that any questions have been answered and that you understand the study. If you have any questions or concerns about your rights as a research subject, call the Committee for the Protection of Human Subjects at (713)500-3985. If you decide to take part in this research study, a copy of this signed consent form will be given to you.

____

Participant's Name (print)

____________________________ ____________________________

Signature Date Time

____

Witness or Investigator's Name (print)

____________________________ ____________________________

Signature Date Time

This study (HSC-SHIS-04-008) has been reviewed by the Committee for the Protection of Human Subjects (CPHS) of the University of Texas Health Science Center at Houston. For any questions about research subject's rights, or to report a research-related injury, call the CPHS at (713) 500-3985.

APPENDIX D: CPHS RENEW APPROVAL

THE UNIVERSITY *of* TEXAS
HEALTH SCIENCE CENTER AT HOUSTON

The Committee for the Protection of Human Subjects
Office of Research Support Committees

7000 Fannin, Suite 750
Houston, TX 77030

Dr. Jiajie Zhang
UT-H - SHIS - Health Informatics

NOTICE OF CONTINUING REVIEW APPROVAL October 18, 2005

HSC-SHIS-04-008 - *The Interaction Between Internal and External Information in Information Searching*

PI: Jiajie Zhang

PROVISOS: Unless otherwise noted, this approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered at this meeting, e.g. study documents, informed consents, etc.

NOTE: If this is an investigator-initiated medical intervention study, or if the PI holds the IND/IDE applicable to this study, and no one else has registered this trial on the national registry, you are encouraged to register at www.clinicaltrials.gov in order to publish results in one of the key peer-reviewed journals. For further information contact Catey Carter at 713-500-6517.

APPROVED: By Expedited Review and Approval

APPROVAL DATE: October 18, 2005 **EXPIRATION DATE:** 9/30/2006

CHAIRPERSON: Anne Dougherty, M.D.

Upon review, the CPHS finds that this research is being conducted in accord with its guidelines and with the methods agreed upon by the principal investigator (PI) and approved by the Committee. This approval, subject to any listed provisions and contingent upon compliance with the following stipulations, will expire as noted above:

CHANGES: The PI must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.

INFORMED CONSENT: Informed consent must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. Attached is the approved and validated informed consent form. You must discard all previous informed consent documents being used and replace them with this stamped validated version. **Please note that only copies of the appropriately dated, stamped approved informed consent form can be used when obtaining consent.**

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent documents if required, in a manner which ensures subject confidentiality.

APPENDIX E: MORE EXAMPLES OF INTERFACE DESIGN