INVESTIGATING GRAPHICAL USER INTERFACE USABILITY ON TASK SEQUENCE AND DISPLAY STRUCTURE DEPENDENCIES

ABSTRACT

Designing Graphical User Interfaces (GUI) requires the consideration of task sequence requirements (sequence of operations arising from task structures and application constraints) and display structure (layout of the elements of the interface) relationships. The basic purpose was to understand the usability differences of the interfaces through efficiency, motor performance, and search performance.

Thirty-two subjects performed experiments in four groups. The experiments differed in display structure and compatibility of task sequences. Subject mouse actions, mouse coordinates and eye positions were recorded. The derived measures, click efficiency, mouse traversal and eye visits to different areas of interest (namely the tool, object, and goal), were analyzed in a repeated measures factorial design with compatibility and display structure as the between subjects factors and phase of learning as the within subject factor.

A significant interaction between compatibility and phase of learning ($p<.01$) was observed. Mouse traversal per unit time increased significantly ($p<.05$) across phases of learning. The phase of learning affected the number of eye visits for all groups. Compatibility had a significant (($p<.005$) effect on the average processing time during search. The results establish that the compatibility of task sequence requirement with the display structure affecting the performance of subjects and hence the usability of the interface was thus obtained. However, through learning, subject performance showed considerable improvement and the effects of task sequence and display structure diminished at final stages of user learning.

Based on this evidence, a systemic structural activity approach was used to develop a model of human performance on the eye movement and mouse action data. This structural model of human performance is defined as an algorithm and can be used for estimating complexity of task performance. In this study only the assumptions for development of the model and the formulation of the model are explained as an application of the results of the study. The study hence served a dual purpose in the long run: understanding the compatibility of the task sequence with the interface display structure as well as establishing eye and mouse movements as a viable tool to study task performance at human computer interfaces.

INVESTIGATING GRAPHICAL USER INTERFACE USABILITY ON TASK SEQUENCE AND DISPLAY STRUCTURE DEPENDENCIES

by
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To Ma and Baba

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LIST OF SYMBOLS

Symbol	Description
w	Number of trials included in moving average
k	Moving average number
E	Click Efficiency
MT	Mouse distance traversed per unit time
V	Total number of visits to different areas of interest
tv	Time of processing per visit
O	Operator Consists of actions that transform objects energy and information
l, L	Logical operation Determine the logic of selection and realization of different members of algorithm and include a decision making process. Can be designated as *l (single logical condition)* or *L (combination of several logical conditions)*
α	Perceptual operator qualifier *(Receiving information for example* O^{α} *)*
μ	Memory involvement qualifier *(Involvement of memory actions* O^{μ} *)*
ϵ	Executive operator qualifier Executive action in terms of motor performance
O^{ϵ}	Member of Algorithm devised on the basis of operators and qualifiers.
th	Thinking involvement qualifier *(Involvement of thinking action* O^{th} *)*

CHAPTER 1

INTRODUCTION

1.1 Research Motivations And Problem Statement

A graphical user interface (GUI) uses visual features, interaction modes and mental model representations to assist users in performing tasks. The study of the relationships among these features, the task, and the effect of this relationship on user performance is the primary focus of usability engineering. Routine usability evaluations are therefore based on studying user performance of composite tasks supported by the interface. Roberts *et al.* (1998) suggested that most of the usability problems arise from inconsistent user models resulting from design features that are unacceptable in relationship with the task to be performed. The relationship between the task and the way the interface supports the task and hence the development of the user mental model is vital in user interface design.

In Figure 1.1 the interface for file transfer software Ws_FTP® is shown. Figure 1.2 shows the interface for file transfer in Roxio Easy CD creator ®. Considering the fact that the applications are different, the basic task here is the same and consists of transferring a file from one location to another. Due to application constraints and interface features, the Ws_FTP® interface is more difficult to operate than the Roxio Easy CD creator ® interface. One of the reasons is that the user in case of a Roxio Easy CD creator ® can easily get the sequence from the layout of the controls (1,2,3,4 is laid out exactly as the visual scanning order of the display). Although the Ws_FTP® lays out the controls in a similar fashion, the task sequence requirement does not follow a similar pattern. As a result, the user moves back and forth between directories to find the exact file to be transferred (see figure for the possible sequences 1,2,3,4 showing the hierarchy of access). It should be noted that there is no problem of finding the file but getting to the directory location where the file exists.

Another problem with the Ws_FTP® is that there are two locations for the directory, one at the top of the interface and the other at the bottom. This results in more options for users but the availability of the options is not made apparent. This is where the Roxio Easy CD creator ® interface scores higher, by flowing smoothly from top to bottom, according to the task. However, the effect of the task sequence requirement and its relationship to the display on the user performance is not clear.

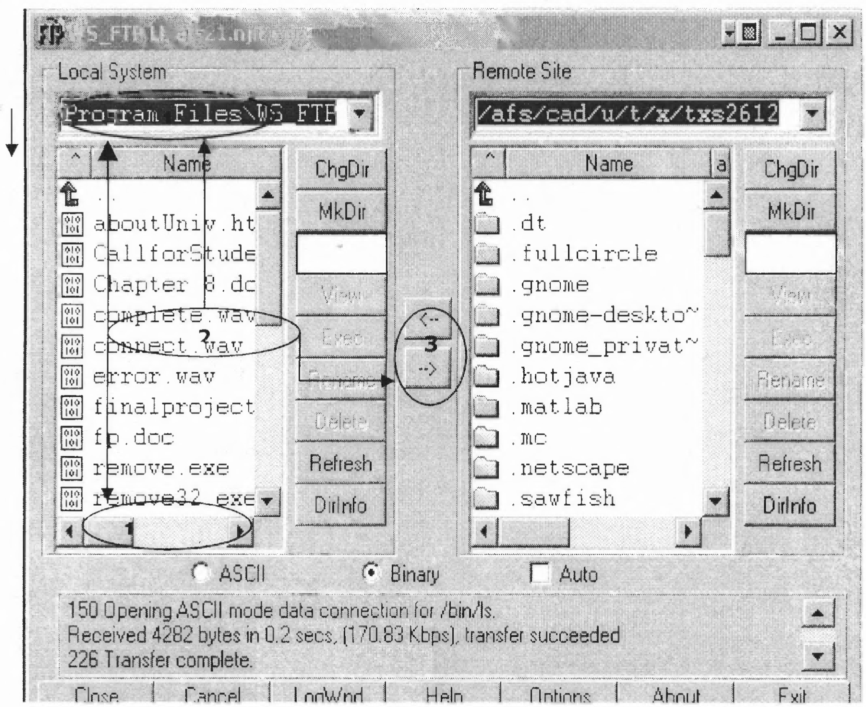


Figure 1.1 Interface for Ws_FTP® (arrows showing sequences and circles showing tools to perform the task of file transfer).

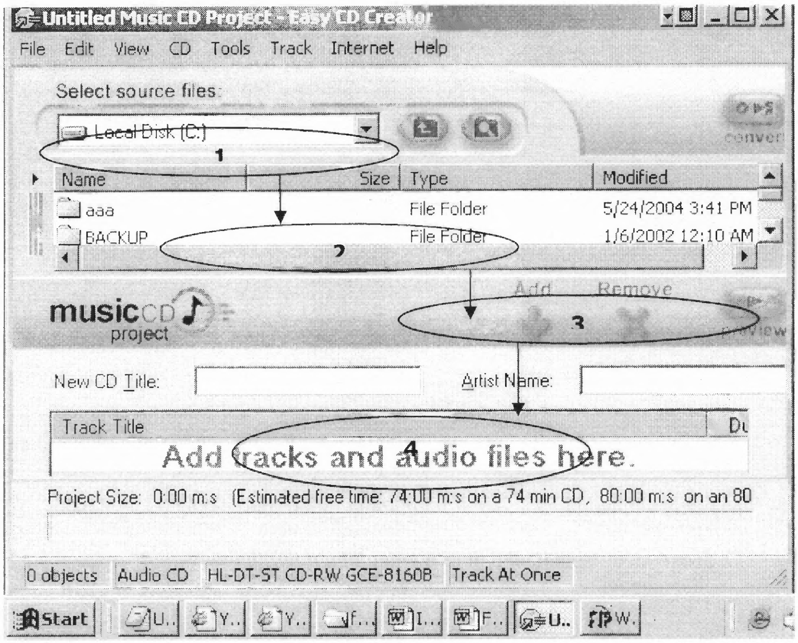


Figure 1.2 Interface for Roxio Easy CD Creator ® (arrows showing sequences and circles showing tools to perform the task of file transfer).

What can be the different possible visual sequences, which can initiate higher usability through efficient task performance, needs to be investigated. In addition, it has to be determined how eye movements and mouse movements can offer us a better explanation of the process so that the Ws_FTP® interface designers will not have to run costly usability tests but directly apply the results obtained as an outcome of studying this relationship.

Karn, Ellis, & Juliano (2000) laid out the advantages of eye tracking in usability evaluations and its ability to assess interface inconsistencies when regular measures of usability (Nielsen & Mack, 1994; Dumas & Reddish, 1994) are not that insightful. It is anticipated that using eye movements as a tool to evaluate usability problems arising from task interface relationship inconsistencies may provide additional inputs to designers. The potential of using eye movement attributes for graphical user interface evaluation has been established in various studies (e.g., Ellis *et al.*, 1998; Kotval &

Goldberg, 2000; Cowen, 2001; Goldberg *et al.*, 2002; McCarthy *et al.*, 2003). Studies of eye and corresponding mouse movements have been used to study menu search (e.g. Byrne, 1999) and target selection (Smith *et al.*, 2000), mainly addressing differences in visual stimuli (location, appearance, grouping or structure). Eye movement, due to its close association to cognitive processes (Yarbus, 1967), when employed in usability evaluations is expected to provide additional insights, although eye tracking still is limited in application to routine software usability evaluations (Goldberg *et al.*, 2002). This is due to the fact that usability professionals in most cases do not have sufficient theoretical background to carry out their studies and employ a bottom up approach to study eye movements for evaluation (Kern & Jacob, 2001).

Tasks on a graphical user interface can be considered as manipulation of symbols represented by the computer for achieving a desired goal. Manipulation of symbols take place by visual encoding of the symbol in relation to the task and subsequent interaction based on an interaction device. Hence, Crowe & Narayanan (2000) suggest that analysis of task performance using eye movements and other interaction data can provide additional insights on the usability of a graphical interface. In fact, they suggested that studying eye movement data in relationship to other interaction data could provide a further comprehensive method of analysis and interpretation.

There is a need to investigate usability measures based on eye and mouse movements when usability differences arise due to inconsistency of relationships between the task and the interface. This thesis studies the effect of interface features on the performance of tasks by the users by observing their eye and mouse movements. The experimental study provides validation of the general research findings and also suggests the use of eye and mouse movements in a variety of usability evaluation methods as well as the study of human computer interactions (HCI). It provides contributions as regards to the relationship of different eye and mouse movements on an interface when task performance is affected due to interface design features like display structure and task sequence requirements. Finally the study introduces action classification and algorithmic analysis methods based on systemic structural activity to present a formalized basis for the study of eye and mouse movements.

1.2 Research Goals

The overriding goal of this research is to investigate a set of usability measures so that the influence task sequence requirement and display relationship on user performance can be studied. Performance is reflected in task execution, motor response and search efficiency, as these are the primary measurable outputs. It is better to specify the goals in terms of sub goals to effectively demonstrate their achievement by this study. These are

- To introduce the concept of task interface relationship arising from task sequence requirement and display structure and its effect on usability.
- To develop an experimental test bed for emulating the aspect task sequence requirement and its relationship to the interface display. The corresponding experiments can then provide eye and mouse movement measures pertaining to the graphical interface elements and observe possible eye mouse relationships in different task interface situations affecting usability.
- To find evidence of the influence of task and interface relationships on these measures. This will provide the efficacy of using eye and mouse movements in task based usability evaluations.

The long-term goals of this research are to develop a methodology for studying task interface dependencies using measures based on eye and mouse movements for usability evaluation of graphical user interfaces.

1.3 Significance Of The Study

Understanding consistent relationships of task sequence requirement and the display of tools can assist designers in implementing design solutions as well as design changes in interface structure and function. The use of usability measures from regular performance as well as mouse movement (motor response) and eye movement (behavior and search efficiency) can provide additional insight not only to the successful mitigation of these problems but also establish other interaction data as a vital source of information. Usability engineers can therefore make a more informed decision is regarding interface modification and development issues when competing options are present.

The methodology for studying eye and mouse movements developed in this study can be extended for use in theoretical frameworks to study human computer interactions. An application of this approach is also demonstrated as the final contribution of the study. The significance of this study lies in the fact that it provides the initial step towards development of a theoretical basis for using eye and mouse movement relationships during task performance to study human-computer activity. Researchers (Harris, 2004; Karwowski, 2004) have already initiated subsequent developments of this theoretical approach to study human computer interactions.

1.4 Organization Of Dissertation

This thesis relies on studies in various fields spanning psychology, usability evaluations and basic human factor principles. The approach is clearly depicted in Figure 1.1 where the structure of the dissertation is presented.

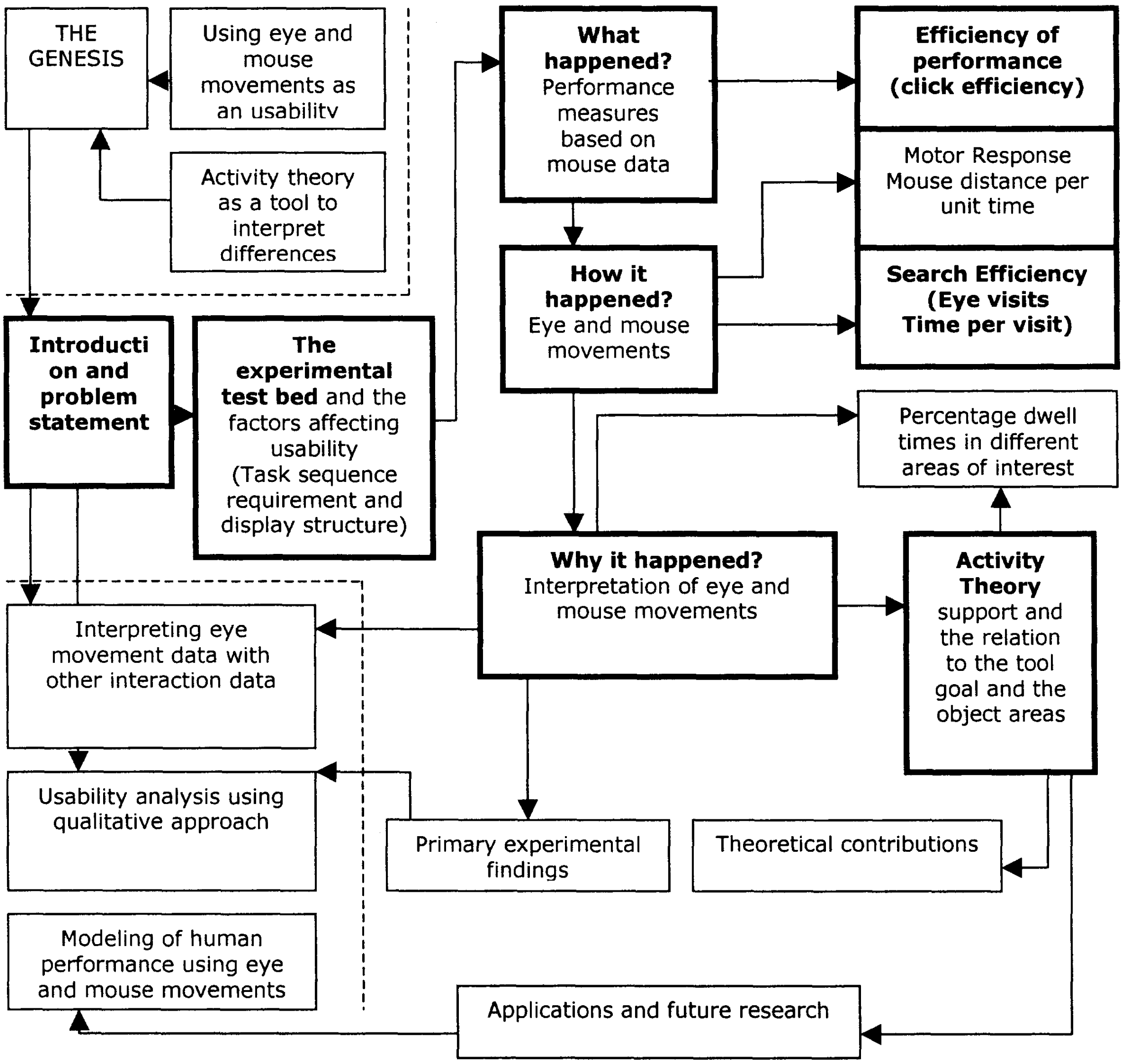


Figure 1.3 Structure of dissertation.

Chapter 2, literature review, first explains the basics of graphical user interfaces and their features affecting task performance. Usability evaluation methods and current studies reporting the use of eye movements in usability evaluation are reviewed. Finally, the notions of task performance (activity, methods, tool, goal, object) were elicited for by systemic structural theory of activity.

Chapter 3 explains the research hypotheses related to the influence of task sequence requirement and display on task performance, motor performance and search efficiency. Chapter 4 discusses the methods: the experimental design, the experiment procedure and the data collection procedures. Measures for dependent variables are formalized on the basis of mouse movement and eye movement data.

Chapter 5 first discusses the results of the various performance measures investigated during the study and their ability to identify the user interface quality levels through experimentally developed hypotheses. Relevancy of the results to the evidence of research hypotheses is discussed. The chapter concludes the results by introducing the final development of the methodology by applying a systemic-structural framework to the study human computer interactions and usability evaluation.

Chapter 6 concludes the contributions of this study and indicates the future prospects. The appendices contain pilot studies and experiment details, data collection details, data compilation and algorithms for data generation, data used for analysis, analysis listings, and an introduction to the basic principles of the theoretical frameworks, which are used in this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Graphical User Interfaces

A graphical user interface (GUI) is a "means by which people and computers communicate with each other" (Bonsiepe, 1968). It makes an application easy, practical, and efficient to use. Norman (1988) suggests that a good GUI design removes the impediment of communication with the computer system and allows the user to work directly on the problem at hand. The quality of the graphical user interface is therefore the single most important issue in designing and implementing systems. The attribute by which this quality is tested for different interfaces is usability.

Usability evaluation is one of the most important activities in a system development cycle. User interface designers are constantly baffled by the ever-increasing demands to bridge the gap between the users and the system designers so that the usability of the user interface can be improved. Roberts *et al.* (1998) suggest three primary issues affecting usability of a graphical user interface. Figure 2.1 shows the user interface iceberg adapted from their book. In Figure 2.1 visual features involve cues, feedback and aesthetics. These features are what the users see. The second level suggests different interaction techniques, which also are relatively visible to the user depending upon their expertise. The more the users interact, the clearer the menu organization and mappings become. Most of the usability problems (reportedly 60%) arise from inconsistent user object models, which are built on the basis of interaction and visual cues from the interface, an issue that can be studied under human factors principles and guidelines (Sanders and McCormick, 1998).

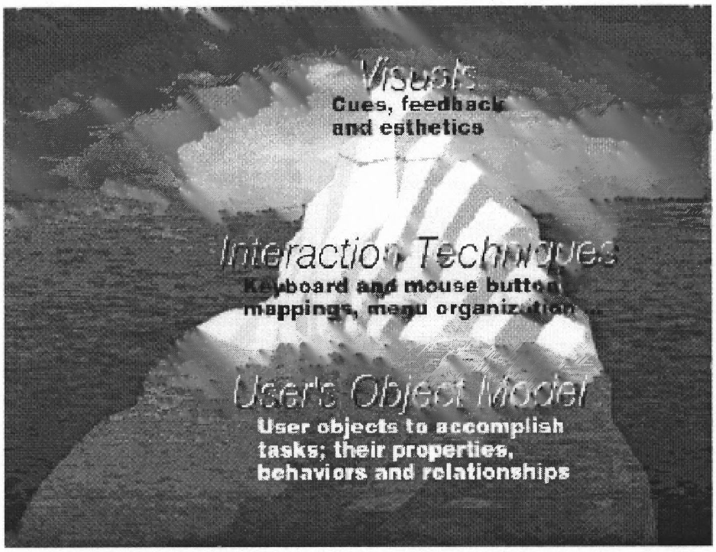


Figure 2.1 The user interface iceberg (adapted from Roberts *et al.*, 1998).

Usability evaluation therefore consists of various methods, which can be used to test the adherence of human factors principles to the design of graphical user interfaces. Research in usability has provided multiple methods to understand the quality of the interface. The use of these methods has led to the development of standards and guidelines based on experiences by former researchers from the domains of human factors, psychology, visual design and ergonomics. Some of these standards include presentation of information, the grouping of information, and information sequencing (Shneiderman, 1997). Proper grouping improves the information's readability and can highlight relationships between the information (Helander, 1998). Mayhew (1992) suggests task compatibility as one of her guidelines for user interface design. Most designers advocate the use of one these de facto GUI screen standards. Studies by these researchers lead to the development of standards and guidelines, which designers regularly use for the design of graphical user interfaces.

Kurosu and Kashimura (1995) in an effort to study the effect of aesthetics on apparent and inherent usability studied that most of the designers employ two types of strategies while designing a graphical user interface. First is the cognitively efficient strategy, which arises form the adherence of design issues to human factors guidelines. They are namely, glance sequence, familiarity and grouping. Glance sequence requires the first element of the display and the operation sequence to be placed at the top left corner of the screen to increase inherent usability. Familiarity deals with the closeness of the metaphors used to depict the different functions on the interface while grouping is associated with the closeness of the type of operation that the elements are used for. The other strategy is the operationally efficient strategy, which requires the elements of the display to be placed in such an order that the desired operation sequence is supported by the interface.

Similar studies by Tractinsky (1997) suggested that the relationship of inherent and aesthetic usability and the effect of aesthetics may be culturally aligned. Various studies of user interfaces have resulted in the formulation of guidelines for design of tasks and their compatibility to the design features of the interface. Designers are therefore concerned with the relationship of the interface and the tasks sequence while designing interfaces, which support a variety of operations and procedures. As a result, the nature of relationships of the interface features like structuring and layout of the interface elements with the designed task sequence becomes an important issue in interface design.

2.1.1 Relationships between Interface and Task

Modern human-computer interfaces not only consist of standard interaction objects like menus, buttons and boxes, but also multimedia presentations like pictures, images and drawings. The layout of all these elements on the screen is to aid the user in performing the task at hand. From the perspective of cognitive ergonomics it is essential to minimize user's efforts directed towards visual scanning, learning and remembering (Pribeanu, 2000). Any primary cognitive task attention devoted solely to the understanding of an interface may interfere with the primary task (Norman, 1988). Hence, minimization of this cognitive load should also be the inherent objective to assist the user task by design.

Consistency is one of the important principles related to the design of interfaces and their relationship with the task to be performed (Grudin, 1989). Dix *et al.* (1998) and Shneiderman (1997) define consistency as a relationship of the interface features with the user's task (familiarity, compatibility), a consistent interaction scenario (dialogue regularity) and a consistent presentation (visual aspects of the interaction objects). Shneiderman states that the first golden rule in dialog design is to strive for consistency mainly of those components of the interface that ask for cognitive efforts from the user. Consistency is not only is it important for dialog design or information presentation but also for interaction methods and task sequences. As a result, Nielsen (1992) has included consistency among the heuristics for evaluation.

Payne and Green (1986) suggest that a user interface consistency favorably affects both the learnability as well as task performance. Tullis (1988) found consistency to be a major issue in the ease of use. Rosenberg (1980) and Vanderdonckt and Gillo (1994) associated consistency with aesthetic design principles. Dix *et al.* (1998) showed the multitude of forms this principle of design does have, since many features of the interface could be discussed in terms of consistency. For example, familiarity is a form of consistency with the real world, while generalisability is a form of consistency with other systems and applications. Also, Shneiderman (1998) says that consistency is not a concept as such, but related to something. For example, visual consistency is affected by the spatial organization of the screen layout and the attributes of visual objects, whereas procedural consistency is affected by the required operation sequence for the task to be performed. Consistency thus is a basic principle for the design of user interfaces.

HCI research is therefore primarily concerned with developing principles, models and methods to assist software designers to construct systems that people find useful and usable while performing tasks. These systems represent a consistent structure and mode of operation. Hamilton (1999) developed a set of principles aimed at structuring task models, user interfaces, and dialogue structures.

Two of the principles for the design of task structures and their resultant user interfaces and human-computer dialogues are Categorical Structuring and Procedural Dependency. Categorical Structuring states that the grouping of similar objects results in subsequent grouping of actions on these objects during interaction. Procedural Dependency states that in carrying out actions people will form associations between those procedures and actions that are sequentially related. Sequencing relations emerge in tasks through the nature of the domain and goals to be achieved. When these sequentially dependent actions are reflected in the user interface/dialogue structure, quicker and more accurate task executions will result.

Hamilton (1999) used these two principles to generate hypotheses with quantitative and qualitative predictions of task performance. Some of his conclusions are worth mentioning. Actions should be categorized according to their sequential relations and this should be reflected in the user interface display through the temporal and perceptual properties of the user interface design. Users can, and do, follow the user interface structure to build their own task knowledge structures provided that the user interface supports a task structure. Where the user interface does not support a principled task structure, the users will impose their own task structure but this will take longer to achieve and their performance with the user interface will be slower than if the interface reflected a principled task structure.

The importance of this principle in graphical user interface is due to the fact that many users now expect certain modes of operation in all GUI. For example, most users expect the top of the screen to contain the headings for the pull-down menus (Sears, 1998). Studies show that most users initially scan the screen starting at the upper-left corner. This corner should be the obvious starting point for applications invoked from within the window. This permits a left-to-right and top-to-bottom reading, which is standard for Western cultures. Since the optimum sequence for screen presentations is a collection of various factors, including sequence of use, it provides the user with a guide to perform the task in a natural flow. Users therefore are inclined to build up a mental model of the interface on the basis of the interaction and the visual structure. It is therefore critically important to adhere to human factors principles, as it would ensure the formation of consistent mental models in users while performing tasks on the graphical user interface.

2.1.2 System Constraints And Its Effect On Task Sequence

Leffingwell and Widrig (2000) define constraints as "a restriction on the degree of freedom we have in providing a solution". Tasks are considered to be "states in the working process" as a part of the workflow. In a study on sources of constraints and their effect on devices and applications, Burgÿ and Garrett (2002) defined task constraints as those attributes that restrict the interaction between the user and the device, such as a task that requires both hands of the user. Constraints of the application influence the user interaction by demanding different navigation. There are domain specific applications, such as construction or manufacturing applications and general applications that for example support the "back office" processes. Furthermore, different application structures or software architectures cause different behaviors of the software. Finally, the application constraint category holds the actual interface / interaction layer, i.e. the interface to the user of the device.

The constraint either in the form of the task or in the form of the application translates to the design of graphical user interface and the user is therefore required to understand the requirement on the basis of interaction or training. When the task requirement or the constraint matches the mental model of task performance of the user, then a high usability is ensured. The study of constraints, their translation to task sequences and the relationship to user interface display elements has been a continuous area of research.

The task sequence requirement in user interfaces is a result of the constraint of the system or the application used to develop the system. These task constraints are inevitable and hence their implementation needs special care so that the usability of the interfaces is not compromised in the process. This is important due to the fact that a user builds up an idea of the system and its functions through interactions and confrontation with the constraints and in the process learns the task sequence requirement thereby building up the task model in the process. This generally translates to the mental model of the system. Inconsistent mental models can hinder efficient performance and hence the usability of the system.

2.1.3 Mental Models And Task Performance

Mental models are representations of reality that people use to understand specific phenomena (Johnson-Laird, 1983). As people gain knowledge of the systems they use they acquire an understanding of the system's behavior and on this basis are able to develop theories about the inner workings of the system (Olson, 1992). They gradually form a working model of the system, which is dynamic and constantly evolving on use. This is what is known as the mental model. Norman (1983) describes it as follows: "In interacting with the environment, with others, and with the artifacts of technology, people form internal, mental models of themselves and of the things with which they are interacting. These models provide predictive and explanatory power for understanding the interaction." Holland *et al.* (1986) suggest that mental models are the basis for all reasoning processes. As a result mental models provide dynamic reflection of situation and include conscious and unconscious mechanisms during task performance (Bedny, Karwowski & Jeng, 2003, 2004). The inability of designers to get past system constraints and their implementation in application results in the design of interfaces which can lead to consistent or inconsistent mental models at the initial use. As a consequence, the relationship of the tasks users perform and the interfaces they use to perform them are significant in influencing the usability of the system. Usability and usability evaluation provides an understanding of how the above-mentioned relationships of task and interfaces and the factors affecting the design of task and interfaces can be improved.

2.2 The Concept Of Usability And Usability Evaluation Methods

Usability evaluation is the primary method by which it is possible to understand the quality of the graphical user interface when it comes to adherence to human factors principles. In case of principles affecting task performance, testing can be done by observing users performing a set of representative tasks at the interface. The unique nature of Human Computer Interaction has created a separate field of Usability Engineering. The previous two decades have seen a prolific research in usability evaluation methods to develop and improve the graphical user interface.

The ISO 9241-11 draft standard defines *Usability* is as the "extent to which a product can be used with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241). Figure 2.2 depicts the framework of usability in the light of the product features, the goals of the system and the desired properties that are required of the system or the product for having a better usability.

Many attempts have been reported to analyze usability in more practical measurable terms. For instance, in (Nielsen, 1993) usability is analyzed in terms of " *Easiness and speed of learning of system use, efficiency to use, easiness to remember system use after certain period of time, reduced number of user errors and easy recovery from them, subjective satisfaction of users.*"

Possessing high usability requires adherence to certain attributes, which can make it easier to perform the task in a particular context of use. Hence usability cannot be measured in isolation.

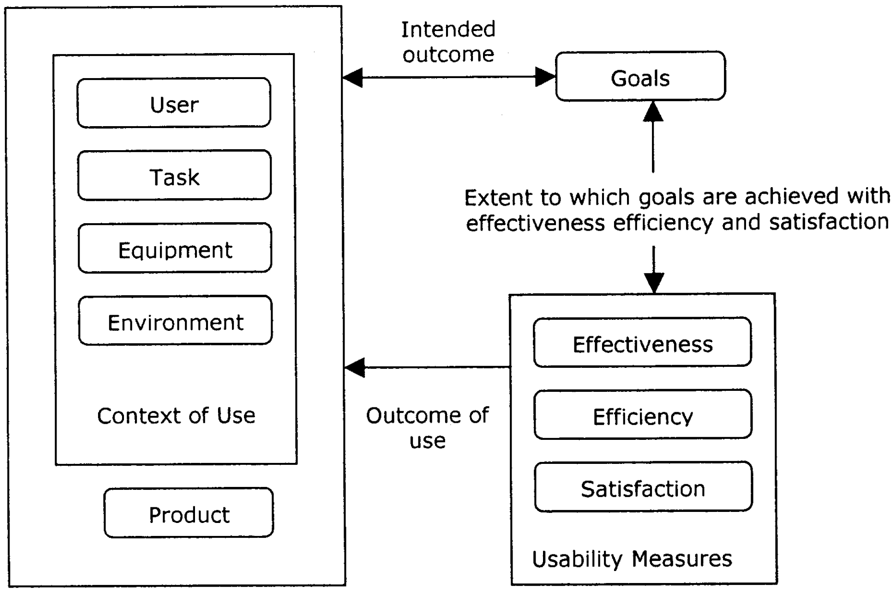


Figure 2.2 Usability definition frameworks according to (ISO 9241-11).

Table 2.1 defines the measures related to the attributes of effectiveness efficiency and satisfaction. Obtaining these measures requires various methods, which have been laid out in ISO 9241.

Table 2.1 Examples of Measures of Usability (from ISO 9241)

Usability objective	**Effectiveness measures**	**Efficiency measures**	**Satisfaction measures**
Overall usability	• Percentage of goals achieved; • Percentage of users successfully completing task; • Average accuracy of completed tasks	• **Time to complete a task;** • **Tasks completed per unit time** • **Monetary cost of performing the task**	• Rating scale for satisfaction; • Frequency of discretionary use; • Frequency of complaints

These measures can be obtained by various methods, which are discussed below:

(a) By **analysis of the features of the product**, required for a particular context of use. Usability could be measured by assessing the product features required in a particular context.

(b) By **analysis of the process of interaction**. Usability could be measured by modeling the interaction between a users carrying out a task with a product. However, current analytic approaches do not give very precise estimates of usability. As the interaction is a dynamic process in the human brain, it cannot be studied directly.

(c) By **analyzing the effectiveness and efficiency**, which results from use of the product in a particular context, and measuring the satisfaction of the product users. These are direct measures of the attributes of usability. If a product is more usable in a particular context, usability measures will be better.

Usability Testing uses different methods, which are user dependent. Most of the studies require subjects or participants involved in some form of task performance, which is then evaluated against the user interface. Out of the numerous usability methods in practice we discuss two methods in detail, which bear close resemblance to the use of eye tracking and used in this study. The first method is performance measurement. The second method is logging of actual use.

Performance Measurement: -This usability testing technique is used to obtain quantitative data about test participants' performance when they perform the tasks during usability test. This will generally prohibit an interaction between the participant and the tester during the test that will affect the quantitative performance data. Quantitative data is most useful in doing comparative testing. To obtain dependable results, at least 5 user participants are needed, while 8 or more participants are desirable (Nielsen, 1993).

Logging of Actual use: - Recording of the interaction of the users during system use. This can provide the exact sequence of the operations performed by the users during task performance and can help in understanding usability.

Recent trends in usability evaluation have incorporated eye movements as a tool to understand the user performance not only in terms of efficiency of execution but also in terms of cognitive efficiency or dispatching of mental resources. The fundamental reason behind use of eye movements in usability evaluation is its association to cognitive process. This is discussed in the next section.

2.3 Eye Movements And Its Use In Usability Evaluation

According to Yarbus (1965), motions of eyes do not simply provide the position of eyes on different objects and subsequent foveating but also is involved in formulation of a perceptual image as well as the development of cognitive processes. In an extensive study, Yarbus showed that the perception of a complex scene involves a complicated pattern of *fixations*, where the eye is held (fairly) still, and *saccades*, where the eye moves to foveate a new part of the scene.

The initial studies of Just and Carpenter (1976) established the fact that eye movements can be used to investigate the different cognitive process occurring in individuals while performing a particular task. Just and Carpenter (1976) used high frequency eye movement data for understanding what information people use while performing problem solving tasks by assessing the amount of time it takes to process information. They investigated the relationship between the locus duration and sequence of eye fixations and the activity of the central processor.

This correspondence of fixations to cognitive processes is the basis for a whole body of research using eye movement behavior to explore different cognitive theories and models (Kieras & Polson, 1988). It should be noted that, even if there is a time lag between the fixations and cognitive processing and subsequent generation of new target goals, the pattern of the eye behavior still corresponds with cognitive processes. Short fixations after long saccades suggest a survey function while long fixations and small saccades are interpreted as detailed feature detection (Nodine, Carmody & Kundel, 1978). At least three processes are assumed to take place within the 250-300 m sec of a typical fixation (Viviani, 1990). It is most likely that the three processes, the analysis of the visual stimulus in the foveal field, the sampling of the peripheral field, and planning of the next saccade, are carried out concurrently.

Eye movements are therefore, at the very least, tags or experimentally accessible quantities that scientists can observe to understand underlying processes of cognition (Stark & Ellis, 1981). Moray and Rottenberg (1989, p. 1319) suggested that eye movements were considered to give "considerable additional insight into the nature of process control information processing" compared to traditional measures of insight.

Rayner (1992) pointed out that, eye movements are not a perfect indicator of cognitive processes they are a good index of the moment-to-moment online processing activities that accompany visual cognitive tasks. As a result eye movements in many situations have been assumed to be predictors of attention. Attention shifts in most cases is associated with shifting of eye in corresponding area. At the same time direction of eye sometimes does not coincide with attention.

Pushkin, (1965) studied eye movements during chess play and discover that they can be associated not only with the perceptual process but also be involved in operative thinking. Mental imagination of objects increases micro motions of the eyes (Bobrova, Khomskaya, 1968, Zinchenko, 1969). Therefore, eye movement is associated with the imaginative process. In goal directed activity eye movement can be used as a predictor of human attention.

Henderson (1993) described two different models for eye movement and attention. The first model is sequential in nature, which describes attention as being "directed to the specific location towards which the eyes will move prior to the impending saccade". It is important to note that *attention* is shifted to the new location *before* the saccade that moves the gaze to a new part of the scene is initiated, and thus the movements of the eyes should not be considered as the selection process itself, but merely as the outcome of attentional selection processes preceding actual eye-shifts. (Theeuwes, 1993) In the second model he describes attention as being "allocated to all locations in the general direction of the impending saccade rather than to a specific target location". Various studies indicate that it is possible strategically to focus attention to smaller areas of the visual field (Eysenck & Keane, 1990). Researchers have thus used eye movements as an insight to the person's thoughts and intended actions (McNight and McNight 1991). This correspondence of eye movements to cognitive processes and human activity offers a basis for usability evaluation using eye movements.

2.3.1 Eye Movements As A Tool For Usability Evaluation

The tracking of eye movements has been a familiar method to researchers in a variety of studies. Fitts (1950) used frame-by-frame analysis of video of the pilots face to study task performance on the display of the cockpit. In spite of their labor-intensive method some of the conclusions were groundbreaking and provided solid background to future researchers in visual search and usability.

Three important conclusions are worth noting which are closely related to this study. First, fixation frequency measures the importance of a display. Second, fixation duration is attributed to the difficulty of information extraction and finally the pattern of transition between display elements is a measure of display efficiency.

In the 1980s work in this area initially focused primarily on disabled users (e.g., Hutchinson, 1989; Levine, 1984). Since then, researchers have used eye tracking to investigate usability extensively (e.g., Benel, Ottens & Horst, 1991; Ellis *et al.*, 1998; Cowen, 2001).

Current studies of eye movement in usability include scan path characterization as a usability metric (Kotval & Goldberg, 1998) optimal sequence matching for scan path and fixation sequence analysis (Josephson & Holmes, 2002) and task level, screen level and object-level analysis of eye movements (Goldberg *et al.*, 2002). Many usability studies have incorporated eye tracking and indicated a difference between novice and more experienced participants (Fitts, Jones & Milton, 1950; Crosby & Peterson, 1991; Card, 1984; Altonen, *et al.*, 1998) and individual differences (Yarbus, 1965; Card, 1984; Andrews & Coppola, 1999). Eye tracking might be a useful tool to study repetitive or well-practiced tasks and "power usability" (Kern, K., Perry & Krolczyk, 1997) and the process by which people evolve from novice to expert users.

In spite of these studies Kern and Jacob (2003) suggest that usability researchers do not always have a strong theory to drive the analysis. As a result eye tracking in usability evaluation requires both a theoretical and practical basis for interpreting eye movement data. In any case, the analysis of eye movement data requires methods for summarization so that they can be used for usability evaluation so that this summarization of eye movement data can be related to the theoretical basis.

2.3.2 Summarizing Methods for Eye Movements

The basic parameters of eye movement, which are of interest to usability researchers, are saccades and fixations as they are attention driven. Goldberg *et al.* (2002) suggests that usability analyses focusing on this micro-level of eye movement data may be too narrow considering the nature of information required. As a result numerous ways of summarizing eye movement data are used. However, the primary step in the data extraction process is to identify saccades and fixations in an eye movement data stream. Salvucci and Goldberg (2000) demonstrated the applicability and quality of various algorithms for identifying saccades and fixations from an eye movement data stream. The researchers suggested that there is no standard method for identifying the fixations and saccades. The choice of a particular method was dependent on the type of data available and the parameters that could be obtained from the data.

Area-of-interest fixation identification uses only those fixations that occur within specified target areas known as area of interest. The target areas are rectangular regions of interest that represent units of information in the visual field. These target areas, generally used in later analyses like tracing, keep identified fixations close to relevant targets.

Other methods of summarizing eye movement data include scan paths (Stark & Ellis, 1991), fixation frequency (Kolers, Duchinsky & Furguson, 1981), transition between areas of interest (Fitts, Jones & Milton, 1950; Hendrickson, 1989; Goldberg *et* *al.*, 2002) and scan path characterization (Kotval & Goldberg,1998). The most widely used metric to assess the relative importance of various screen areas is percentage gaze or percentage dwell time and are used regularly by researchers for aircraft cockpit studies (Fitts, Jones & Milton, 1950; Harris & Christhilf, 1980), computer menu organizations (Hendrickson, 1989), web page viewing (Benel, Ottens & Horst, 1991), web search tasks (McCarthy *et al.*, 1998), low level flight navigation (Flemish & Onken, 2000) and web based purchasing (Albert, 2002).

2.3.3 Study Of Eye Movements And Mouse Movements

Card (1984) and Nilsen (1991) extensively studied menu selections by users and obtained a higher proportion of eye movements and associated visual processes in the study rather than pointing times using the mouse.

Later advanced studies by Byrne (1999) and Hornof (2001) suggested marked relationships between eye and mouse movements. However, both the researchers have expressed the superficial nature of their investigation in terms of the relationship of eye and mouse movements. Their studies were mostly attributed to the validation and subsequent improvement of the models predicted different cognitive architectures.

A recent study on eye and cursor movement relationships, done by Smith *et al.* (2000), produced various results in terms of eye and cursor movement relationships and attributed the nature of movements to the individual differences of visual search pattern. Also task related differences persisted among individuals and a variety of search patterns were observed.

To study eye and mouse movements, a theoretical basis needs to be introduced. Activity Theory due to its basic foundation on the unity of cognition and behavior provides a theoretical basis, which can be used to interpret the results obtained by studying the eye and mouse movements together. Specifically, systemic structural theory of Activity (Bedny, 1997) advocates the use of the principle of unity of cognition and behavior as a key aspect in the study of Human Computer Interaction (Bedny, Karwowski, Bedny, 2001). The next section deals with some of the issues in systemic structural analysis, which was used in the interpretation of eye and mouse movements.

2.4 The Framework of Systemic Structural Analysis

The term systemic-structural approach is used because it describes the structure of activity as a system. Different interdependent approaches for studying the same activity are organized as stages, sub-stages and levels of analysis. All of them require different units of analyses, which permit to describe activity not only from different perspectives but also with different levels of detail. The systemic-structural approach considers activity as a multidimensional system and describes it by using diverse experimental methods and formalized descriptions.

Activity during task performance is a multidimensional phenomenon, which cannot be described completely by one single "best" method. As a result, the study of activity can be successful only by employing a set of interdependent methods analyzing the activity from different points of view. The previous chapters identified the dynamic relationship of eye and mouse movements in a graphical user interface task scenario. The study of human computer interactions from a systemic-structural perspective requires the aggregated study of eye and mouse movement measures and their relationships to completely understand the developed task structure.

Systemic-structural Analysis has been applied to a wide variety of task and applications. However, its application to the study of usability and human computer interactions is only being recently realized. Table 2.2 shows the various areas where Systemic Structural Theory of Activity has been applied recently.

Table 2.2 Applications of Systemic Structural Analysis for Study of Human Performance

Application	**Task Studied**	**Authors**
Manufacturing		Bedny, Seglin & Meister (2000)
Underwater machines	Diver Equipment	Bedny (1997)
Flight Safety	Pilot training task	Karphukina & Jeng (2003)
Individual style of Personality		Bedny & Seglin (1999)
Sports	Gymnastics	Bedny & Seglin (1999)
Situation Awareness		Karwowski, Bedny & Jeng (2003)
Computer task	Drawing task	Sengupta &Jeng (2003)

A graphical user interface can also be considered as a system of interrelated elements, which are functionally organized to represent the internal system. The interaction between the graphical user interface and the human system generates the inputs to the system and the outputs from the system. As a result the phenomenon of task performance on the graphical user interface can be considered as an interaction of two systems. To study the interaction between these two systems, it is customary to study both systems as well as the flow of information between the systems which is either in the form of display changes in case of the interface and mouse movements and clicks in case of user output (considering output from a human system). Since users observe and initiate the changes through eye movements, most of the activity on the graphical user interface can be studied by observing users' eye and mouse movements.

2.4.1 Systemic-Structural Theory Of Activity During Task Performance

The theoretical basis for studying human activity in graphical user interfaces and human computer interactions is provided by Bedny, G. Z., Karwowski, W., & Jeng, O. -J., (2001). They suggest that activity during performance of computer-based tasks can be considered as a complicated structure comprising of different hierarchically organized elements. A task may be defined as a logically organized system of mental and behavioral actions directed to an ultimate task goal. A task is considered to be a basic object of study. They also introduce a triangular schema to analyze human activity (see Figure 2.3).

In this schema, the object and goal are treated as distinct components and not only the subject – object relationship, but also inter-subjective relations are represented. The broken circles in the Figure 2.3 indicate that subject-object interaction may be either direct, or mediated through the use of external instruments.

By the same token, inter-subjective interaction may be direct (speech, gesture), or instrumentally mediated (e.g. telephone, email). In both object-and subject-oriented actions, direct interaction should not be taken as implying a complete absence of mediating instruments; rather, in such cases the subject employs "internal" tools.

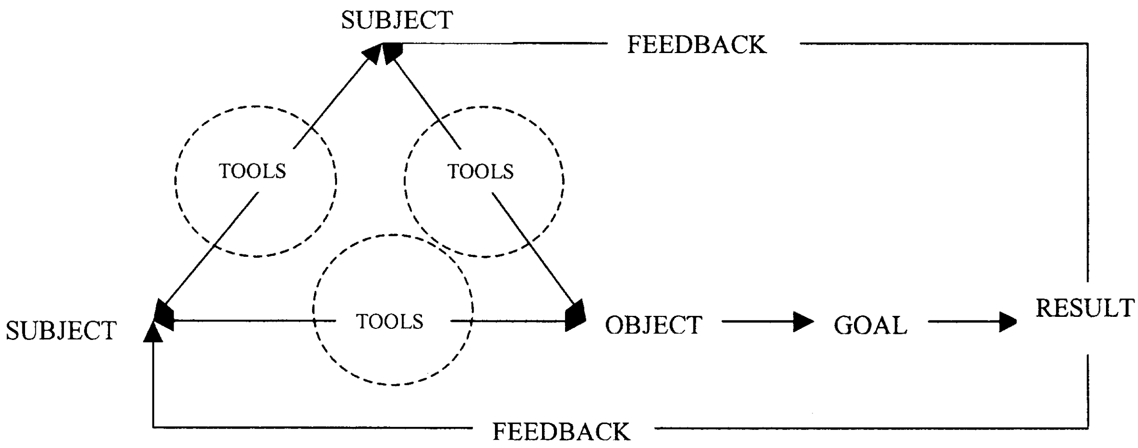


Figure 2.3 Schema of activity.

In Activity Theory (AT), the subject is always understood as a socially constituted individual, in possession of internal, psychological tools acquired during ontogeny. The schema only illustrates the presence of an external tool; internal tools are assumed as a condition of subjectivity.

The diagram also distinguishes between the concepts of goal and result. Whereas the goal is a primarily cognitive mental representation of the desired future state of the object, the result is the actual outcome of activity. Clearly, the result of an activity may coincide with the goal, or it may not. It follows that the subject's attempts to reach a desired result align with their established goal; if the actual result of an activity does not coincide with the subject's goal, then she or he must reformulate their strategy for goal achievement, or reformulate the goal itself. This process of continual adjustment requires the presence of feedback influences, and implies that activity is organized according to principles of self-regulation. These feedback influences are also presented on the schema, as arrows connecting the result with the subject.

2.4.2 Elements Of Activity During Task Performance

The basis of the triadic schema is derived from two aspects of human performance during human computer interaction. First aspect relates to the major elements of activity and second is the learning of task by self-regulation of activity during task performance. These two concepts are realized in our experimental study. Elements of activity during human computer interaction task performance are conceived as a multidimensional system (Bedny & Karwowski, 2004). Activity during task performance includes the following basic elements. The subject of an activity is an individual who performs in accordance with conscious goals and the task embedded in these goals. (see Figure 2.4).

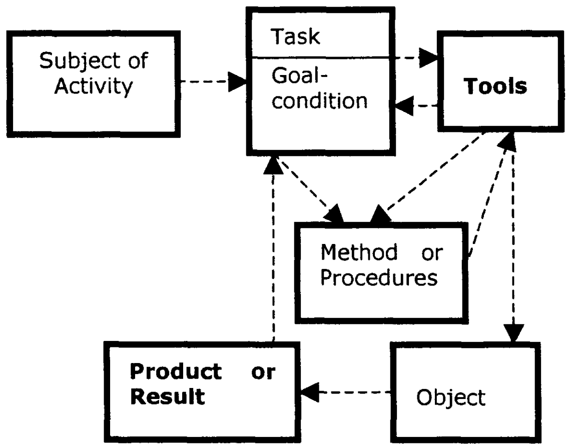


Figure 2.4 Major elements of activity.

The tool is what the user uses to modify the state of an object towards achievement of the goal. The intermediate state of an object can affect the choice of tool. However, similar results on repeated use may render the tool to be internalized and the user then has least cognitive overload in performing the operation. Once the tools are internalized they can be used to carry out imaginative action or actions that are not physically taking place but mentally represented by the user.

The object is what is modified and explored by a user according to the goal of activity. Modification or exploration include not only physical transformation, but also the classification of objects according to required goals, the discovery of features of the object that correspond to the goal of explorative activity, and so on. Objects may be either concrete or abstract. Abstract objects are e.g. signs, symbols or images, and their constitution as entities transformed by the user in accordance with goals. This is basically the notion of graphical user interface. Initial, intermediate, and final states of objects may be distinguished while the users perform tasks on a graphical user interface. It is only the desired future final state of an object (document, drawing or program) that corresponds to the notion of the goal of action or activity.

A goal is a conscious cognitive representation of the desired future result of activity. Goals may be accepted in advance, or formulated and specified during activity. Sometimes the goal is very ambiguous during the preliminary stages of task performance; goals may be modified or even entirely transformed during the course of activity. It is vitally important to note that in the absence of a definition of the goal and the task, the object itself cannot be defined. The only difficulty in the concept of goal is its abstract notion during human computer interaction.

Method depends upon logical organization of mental and cognitive actions, which permit users to achieve the desired goal. User interface features which conflict with the method realized by the subject on the basis of the interface structure and appearance can impede the achievement of this goal. The display layout and the sequence of use hence becomes a key issue which can influence human performance and thereby the usability of the interface. The method basically refers to the task sequence requirement that is supported by the interface to perform the task.

2.5 Summary

The literature review introduced the basic idea about graphical user interfaces and the features of these interfaces which affect user task performance and hence usability. Methods for measuring this usability were reviewed and current trends indicate widespread use of eye movements in usability evaluation of graphical user interfaces. A theoretical notion of task performance on the graphical user interface was developed by considering GUI as a system using Systemic-Structural Theory of Activity principles.

The main objective of the study is to first study a set of usability measures derived from eye and mouse movements and then apply systemic structural principles to develop a model of performance for a human-computer task. This can enable us to ascertain the complexity of the task at the user interface. However, to fulfill the long-term goals, the short-term objective of studying the usability measures must be achieved. In the next chapter the research hypotheses and the objectives are developed so that the first step towards using eye and mouse movements in unity to study human computer interactions can be realized.

CHAPTER 3

DEVELOPING THE RESEARCH HYPOTHESES AND OBJECTIVES

3.1 Research Hypotheses

The motivation of the study was to understand how task sequence requirements and display structure impact the usability of a graphical use interface. This led to the following research hypotheses.

Thesis Statement:

Usability differences in graphical interfaces due to relationship between embedded task sequence requirement and display structure affecting user performance can be studied by investigating a set of measures based on eye and mouse movements.

Research suggested the use of standardized usability measures in order to ascertain the interface quality levels. Recent improvements in usability testing and the introduction of approaches using eye movement techniques initiated this research. The terms used in the thesis statement are defined as follows:

Usability of a graphical user interface refers to the ease of use, the efficiency, effectiveness and satisfaction while interacting with the system through the interactive elements on the interface display.

Graphical interfaces are the display based interactive screens or layouts, which aid the user to perform complex tasks supported by a system. The graphical interface makes it easy for the user to control the input and output to the system.

Embedded task sequence requirement refers to the required sequence of performing the operations on the interface display and the sequence of use of the display elements so that proper and successful task performance is ensured.

Display structure refers to the arrangement of the elements on the interface screen. The arrangement of the interactive elements (icons, menus etc.) can influence the understanding of the system operation as users tend to develop a mental model on the basis of both the spatial and the functional qualities of the elements of the interactive display.

The relationship of the task sequence requirement and the display structure can affect the way a user performs a task. This was featured as *compatibility* in the existing literature (see Chapter 2, Section 2.1.1). As a result the ***user performance*** with respect to efficiency of operation, motor response as well as search efficiency may suffer resulting in reduced usability of the interface. Investigating three related research hypotheses can substantiate the thesis statement. Hence the research hypotheses of interest in this study are:

HA: *The relationship between graphical user interface display and embedded task sequence requirement can affect the user* ***efficiency of performance*** *and thereby the usability of the interface.*

Graphical user interfaces are used for performing a set of tasks. These tasks require a standard method of operation for successful completion. This results in a sequence requirement that must be followed. Users develop an understanding of the sequence through the interface display structure. Standard efficiency of performance is measured in ways that reflect the cost of performing the task. If the number of actions (clicks) required to complete the task are higher than required due to the compatibility of the relationship of interface display and the task requirement, then the usability of the interface can be assessed by the click efficiency of the users.

HB: *Interfaces differing in usability due to different task sequence requirements and interface display relationships can affect the* ***mouse traversal rate*** *of the users during task performance.*

Mouse movements reflect the motor performance of the users on an interface. Any disruption in task performance due to usability violations may cause the users to perform the task inefficiently. The usability of the graphical user interface arising from compatibility of task sequence requirement and display structure can be assessed by studying the mouse traversal during task performance. It is expected that an increase in mouse traversal rate will indicate efficient performance due to faster operation and task execution through access of tools.

HC: *Interfaces differing in usability due to different task sequence requirements and interface display relationships can affect the* ***search efficiency*** *(reflected by the number of visits or glances to areas of interest) of users during task performance.*

Since users rely on eye movements to perform the tasks by perceiving user interface elements, eye movements should reflect the performance of the users and the usability level of the interfaces associated with the different task sequence requirements and display relationships. If the compatibility of the task sequence and the display is high then the search efficiency will be high, while a lower degree of compatibility will affect this search efficiency and increase the number of visits made by the users to the different areas of interest. Note the difference of this hypothesis from the previous research. In all studies a search task was studied and the display structure was manipulated to understand the effect on search performance. In this case the focus of study is that the embedded task sequence requirement can also affect the search efficiency and hence usability of the interface display.

The relationship of the research hypotheses with the independent and dependent variables of interest is shown in Figure 3.1.

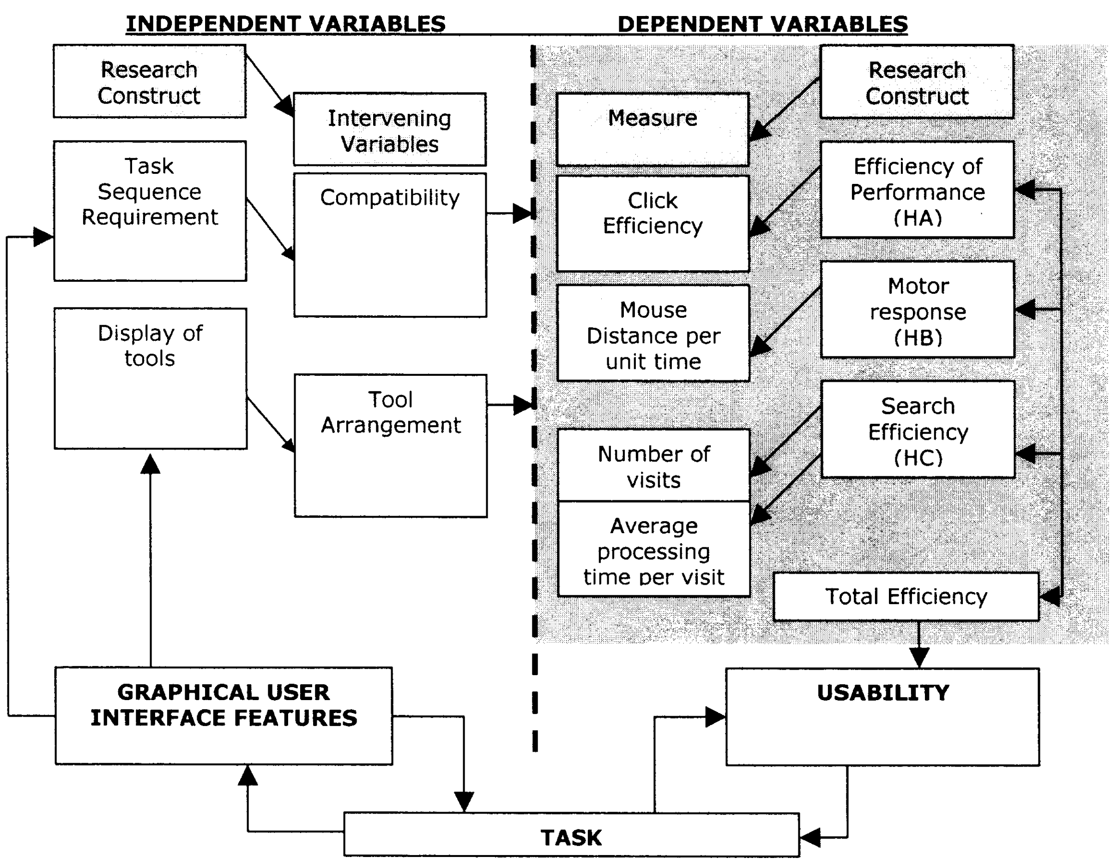


Figure 3.1 Focus of the research study.

The arrows depict how user performance is reflected in the measures under investigation and how monitoring these measures can provide us the usability of the user interface. The measures mentioned in the figure as well as the hypotheses are explained in the next Chapter.

3.2 The Compatibility Of Task Sequence And Graphical Interface Display

It was mentioned that the sequence of use principle affects tool layout arrangements and their compatibility to task sequences. The procedural principle of interface design was discussed in relation to the factors affecting interface usability and task performance. It is expected that tool arrangements (starting either from top or from bottom) provides the task sequence cue to the users according to the sequence of use principle which states that the display layout of tools of a graphical user interface should match the sequence demanded by the task (Shneiderman, 1997).

For example, in the case of content navigation in websites, the menu items are either positioned at the top or at the left (McCarthy, Sasse & Reiselberger, 2003). In the case of procedural interfaces (Burmistrov, 1994) operators rely on the position of the tools to associate them to task flows, and interfaces designed on the basis of task flow are considered usable. This study extends on the results of the previously mentioned studies on task sequences requirements and display layouts and investigates the eye and mouse movements. Based on the structure of the interface, the users derive a mental model of the task and perform the operations on the interface. Examples of regular interfaces having task sequence requirement and interface relationships are provided in the next section along with the areas on the interface being identified as tools and objects.

In the examples below task interface relationships are discussed in detail on the basis of software interfaces used in practice. In addition, the elements of the interface are associated with the theoretical notions of task performance described in Chapter 2, and the same methodology is used in developing the experimental test bed and analysis of the study results. The use of this concept is to identify the relationships of the performance with the eye movements in different areas of interest. The examples below show the activity components: tool, object and goal and how the relationship of the display and the task sequence requirement can affect the usability of the interface.

It is assumed that attention to specific areas on the screen associated with this theoretical notion of task performance reflects the subjects' internal mental process and can be understood from the eye movement behavior in these areas of interest. Hence, when a usability problem exists, the study of eye and mouse movements in these areas can provide an understanding of the difficulties encountered by the user during task performance. In the examples that follow, the areas on regular interfaces that can be associated to these notions of task is demonstrated and the concept of task sequence requirement is illustrated. The examples used are found regularly in standard software.

Figure 3.2 shows an example of task sequence requirement in one of the most commonly used functions in Adobe Photoshop ®. To transform an image it is customary to duplicate the original image first and then work on the duplicate. The constraint or the task sequence requirement thus is strict due to programming limitations but is not salient to the user unless he or she faces it during task performance. However, the implementation of this requirement can be realized in multiple ways. When users do not have any knowledge of the requirement, they are going to impose their own sense of sequence (Hamilton, 1999). This study can provide the answers to the use and implementation of these requirements.

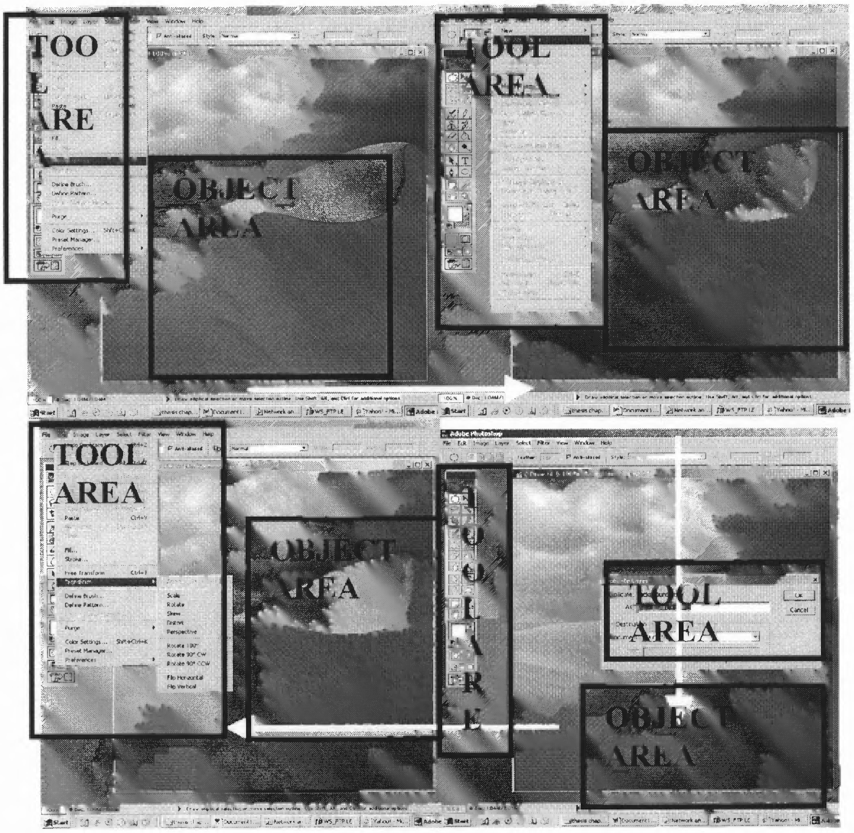


Figure 3.2 Sample task sequence restriction for Adobe Photoshop® Interface.

In the next example the sorting function in Microsoft Excel® is shown in Figure 3.3. A group of column-wise data needs to be sorted according to a particular column. The choices that will do are either the icon button or the menu choice both having the same icons: this creates the wrong notion that the same action will be achieved using any icon. But in this case differences in the functions are observed. The group sorting has to pass through a sequence of selecting the particular column based on which sorting has to be done. This provides an additional constraint as well as frustration to the user when the wrong selection produces an outcome that was not expected.

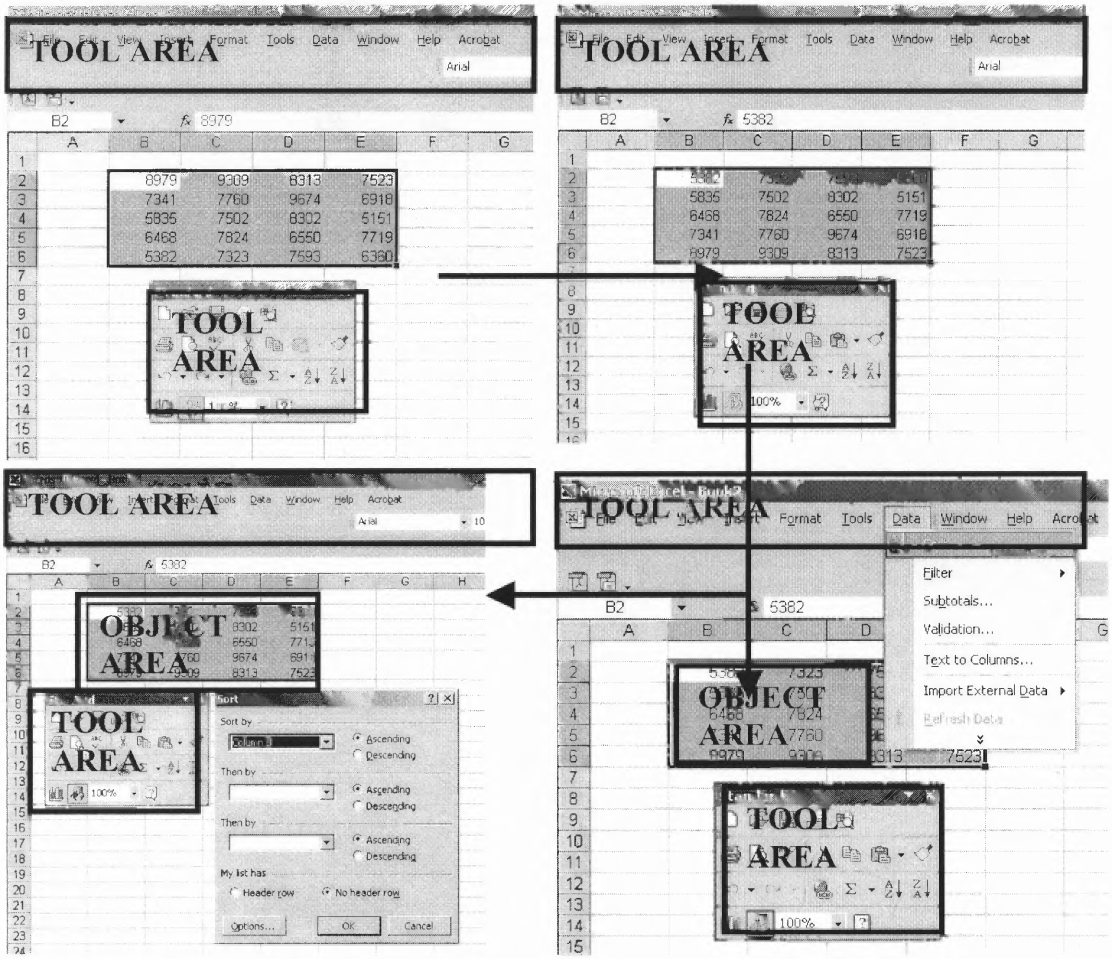


Figure 3.3 Sample task sequence restriction for sort operation in Microsoft Excel®.

Figure 3.4 shows the use of the print function in Microsoft Word. In this case using the icon on the tool bar or using the file-print menu option can activate the print function. However, if the user wants to change the options for printing, e.g., the layout or the number of copies then the menu option has to be used rather than the icon or the tool option. Activating the tool option would result in direct printing without any options being given.

In all these examples, it can be observed that the areas on the interface have been associated with the notion of tool goal and object. Studying eye movements in these areas might provide us an understanding of user performance and hence make an assessment of the usability of the interface in the context of task performance.

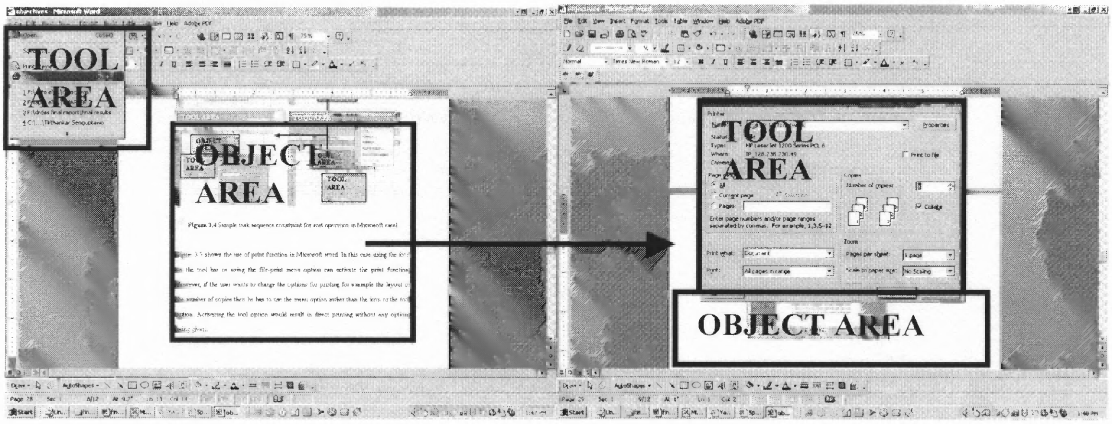


Figure 3.4 Sample task sequence restriction for using Print options in Microsoft Word®.

The difficulty with the task sequence requirement in these examples is caused by the required application constraints. As a consequence, their existence cannot be nullified. However, the options for introducing these requirements can be multiple. The same requirement can be implemented using various design methods. If it is possible to understand which task sequence requirement can be implemented so that the users will seamlessly work through the interface without getting stuck, then the usability can be further improved. The display structure, as it was seen in Chapter 1, Section 1.1, can be a useful cue to the users while performing this type of operations. Although the implementation of complete changes in display structure can be costly, the manifestation of these constraints can be changed initially in the design phase to enhance the usability of the interface. The focus of this research is to understand whether studying performance and eye and mouse movements can provide us an understanding of the proper task sequence requirement in relation to the interface application.

Based on our previous discussion it can be argued that interface features (grouping of tools, multiple interaction sequences) affect task performance and since the attention of the user is focused on these areas of the interface, their difficulty can be understood by studying mouse movements as an indicator of performance and eye movements as an indicator of mental processes. The only difficulty of associating areas, on the interface screen is that general software interfaces have multiple windows and it may be difficult to use this method (Jeng & Sengupta, 2001). However, reducing the granularity of the areas to individual elements and then associating them with the different activity elements can be a possible improvement (Sengupta & Jeng, 2003). Because of this fact and limitations of the eye tracker equipment an experimental interface was designed having a single window layout with three major areas: the tool, goal and the objects.

3.3 Self-Learning Using Exploratory Behavior

The procedural principle in designing user interfaces is associated with another aspect. As users who perform tasks on the interface gradually learn the task sequence through exploratory behavior. The aspect of learning was mentioned by most of the researchers interested in use of eye movements in usability. This is closely associated with the issue of learnability of user interfaces. The ability to support learning is another aspect of usability. In case of task sequence requirements, this issue becomes more prominent as the users tend to adjust their mode of operation as soon as they face any difficulty. Even if the users are not intimated by the existence of this requirement, they will first impose their own rule and finally understand the designed rule on the basis of their errors. This was expected in the study and hence considered as a major factor for understanding any differences in performance.

Activity theory too, suggests that there is a process of skill feedback from the actions during task performance helps in the process of skill acquisition. This was also studied in task based usability evaluation of exploratory learning of LISA (Carroll & Rosson, 1987). Carroll suggested that users are only interested in learning interface features when they face a task, which demands the use of those features and will adjust their perceived task sequence from tool arrangement to the one required by design. Carroll and his colleagues analyzed the learnability of office system interfaces in situations where novice users were given no coaching or training (Carroll *et al.*, 1985). The research demonstrated that most users were willing and able to learn by exploration, although there were individual differences in exploratory aggressiveness. Users are only motivated to explore the interface and learn the features when they are confronted with a certain task.

Learnability is an important feature of a user interface and may be used as an indicator of usability of the interface. The analysis of performance strategies during skill acquisition can reveal extra insight to the difficulty of task performance and hence the usability of the interface. In computer tasks, there is both supervised learning and self-learning or independent learning in which exploratory strategies are important. Sometimes, exploratory activity can be relatively independent of supervision. Any activity has four stages; goal formation, orientation, execution and evaluation. The first two stages are often considered as one and labeled as orientational stage. In structure of activity orientation precedes the execution stage and corresponds to some degree to what

Endslay (2001) designates as situation awareness. Exploratory strategies are particularly important at this stage (Bedny, Karwowoski & Jeng, 2004; in press). Exploratory activity is particularly important in independent learning which is critically important for human computer interaction tasks.

3.4 Objectives Of This Study

The following research objectives were considered for the study:

1. Understanding the concept of compatibility between task sequence requirement and graphical interface display through examples from software in regular use and their importance to usability (Chapter 3, section 3.2).
2. Development of an experimental test bed interface using general user interface elements, a task supported by the interface and associating the interface elements to the notions of task performance described in the theoretical basis in Chapter 2 (section 2.4). This is pursued in the next chapter (Chapter 4).
3. Investigate the eye and mouse movement measures obtained during task performance in this experimental setting so that their conformance to principles of user interface design can be assessed using experimental hypotheses (Chapter 5).

The final goal of this study is to test the previously mentioned hypotheses through a set of experiments and establish a relationship between eye and mouse movements. This can indicate its suitability as a tool to evaluate the usability of a graphical user interface when task sequence requirements and their understanding by users through the user interface display structure affect performance of tasks at the interface. Once this correspondence between eye and mouse is established then further research can be conducted by the application of systemic-structural analysis to the study of HCI using eye and mouse movements.

CHAPTER 4

EXPERIMENTAL DESIGN AND DATA COLLECTION

4.1 Introduction

The first step of the study was to understand the relationship between task sequence requirement and a graphical interface display. This was detailed in Chapter 3(Section 3.2). The next step was to develop a task (Section 4.2) and an experimental interface (Section 4.3), which can act as a test bed for understanding the relationships of interface display structure, the embedded sequence, and the task performance of the user.

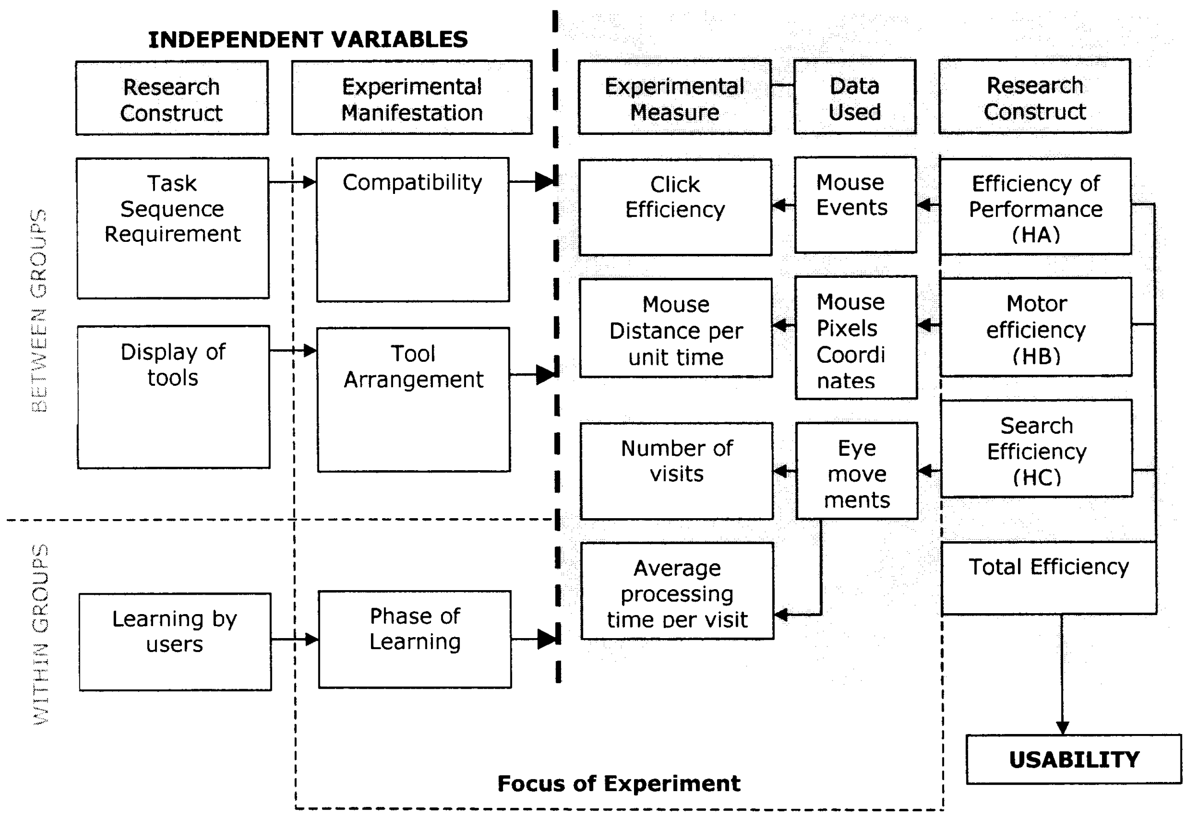


Figure 4.1 Focus of the experimental study and its relation to research objectives.

The relationship between the research hypotheses and the experimental study is depicted in Figure 4.1. The focus of the experiment is on the performance of the users in terms of mouse clicks done to perform the task. Once the experimental task and the interface is designed, then relationships between the interface structure and the display can be realized on the basis of the sequence of operations and the sequence of the display structure. This can only be implemented in the tools or the interactive elements of the display, which are associated with the system operations (in this case the functions supported by the system and represented on the interface by elements like icons, menus etc.; Section 4.4). To accommodate the above, graphical interfaces were constructed with different display structures and task sequence relationships and varying usability levels.

Subjects in different groups were recruited to perform the tasks on the interface and their performance (eye and mouse movements) was monitored. This provided the necessary data required to investigate the research hypotheses (HA, HB & HC).

4.2 Task Design

A simple manipulation of letters form the English alphabet was conceived as the task for the experiment. However, this manipulation consisted of various forms in order to assess how users faced problems regarding the embedded task sequence in the interface. This was obtained by introducing three different features. An important aspect was to make these features as distinct as possible. The features that were considered were

a) Position: the location of the letters with respect to each other.

b) Color: the color of the cell containing the letters.

c) The format of the letters.

These features resulted in three functional groups (based on interface guidelines of functional grouping) in the interface. It is commonly observed in a variety of software that almost all interfaces include functional groups for the users to understand the general functions of a tool group. For example in Microsoft Word ® this is observed in the format group and the alignment group (see Figure 4.2).

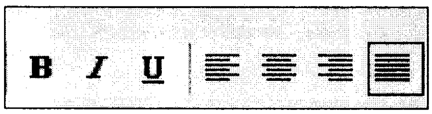


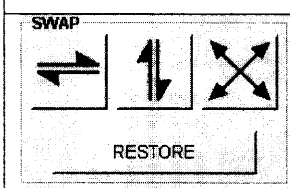
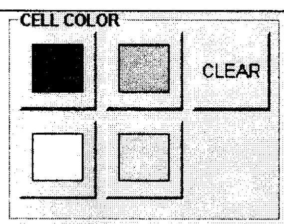
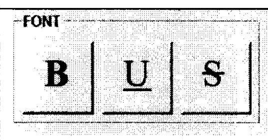
Figure 4.2 Format and Alignment group in Microsoft Word®.

The tools designed for manipulating these features and their functional groupings are depicted in Table 4.1. Their functional grouping and manifestation on the interface is given in Table 4.2.

Table 4.1 Tools For Task Designed As Icons On The Interface With Intended Functional Grouping

Position		Color		Format	
	Swap Horizontal position		Red	B	Bold
			Green		
	Swap Vertical position		Yellow	U	Underline
	Swap Diagonal position		Blue	S	Strikethrough

Table 4.2 Functionally Grouped Structure Of Tools On The Interface

Position	Color	Format
		

4.2.1 Implementation

The task was to impart features to the different letters so that a given arrangement is finally reached. Any number of actions could be possible by the user in this regard, but the user was only instructed to reach the final arrangement. The subject had to follow a sequence to impart the features to the objects. There is a sequence that can perform the task optimally. Any alternative sequence other than the optimal sequence would result in an excess number of actions (clicks) and hence reduce the efficiency of performance.

A sample task

Select cell a→Click blue→Select cell b→Click diagonal swap →Click green →Select c →Click vertical swap →Click underline →Click red →Select d →Click bold →Click yellow. The different subtasks can be performed in any sequence.

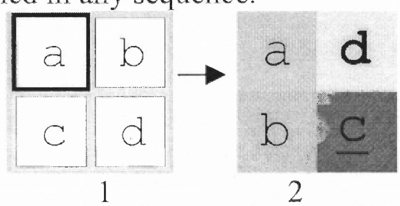


Figure 4.3 A simple task and the tools to be used to do the task.

A sample task is shown in Figure 4.3 shows a sample task and the corresponding stages to obtain a given arrangement from a given initial arrangement. Initially the letters chosen for the task were a, b, c and d. Pilot studies revealed that this initiates a sequence effect biased by the inherent alphabetic sequence in the letters themselves. As a result, uppercase letters with no sequence were chosen for the task so that the subjects get the cue from the features rather than the sequence of letters. The final choice was **Q, W S and D**, which differed both in features and had no inherent sequence that would influence the sequence used by the subject.

4.2.2 Significance In Experiment

The task consisted of manipulating the objects' features available using the tools. As a result letters that were altered in position, color and format are objects in the task. The initial state of the object is without any features. The subjects imparted the features to these objects by using the tools according to the given goal or in this case the arrangement. To study the relative attention to the three aspects of the task it was customary to fix the goal. Variability in the subjective evaluation of goal would result in various representations of the same goal (Sengupta & Jeng, 2003) and hence the focus of the users on the aspects of this study could not be studied on a standard basis.

4.3 Interface

Several considerations were taken into account while designing the interface. They were:

a) The task could be easily performed with only the mouse click as the other sources of input ware restricted for obtaining the eye movement data.

b) The final arrangement should be shown on the interface so that the user has no ambiguity in terms of the goal.

c) The different functionally relevant areas should be designated clearly enough so that the various attention shifts between the goal, objects of manipulation and the tools are clearly identifiable for analyzing the eye movement data.

The interface is given below in Figure 4.4. It has three functionally relevant areas; the tool area, the object area and the goal area. The tool area, consist of the tools described previously in a functional grouping. The object area consists of the letters to be manipulated, while the goal area consists of the arrangement to be achieved as a requirement of the task.

Associating areas of interest to elements of task performance based on theory of human activity was used in previous studies (Jeng & Sengupta, 2001), which suggested that a user only focuses in task relevant areas while performing tasks on an interface. For a generic interface these areas were translated form theoretical notions of task performance based on Activity Theory approaches to human computer interactions (Bedny, Karwowski & Jeng, 2001). The experimental interface was designed based on this theoretical notion (see Figure 4.4).

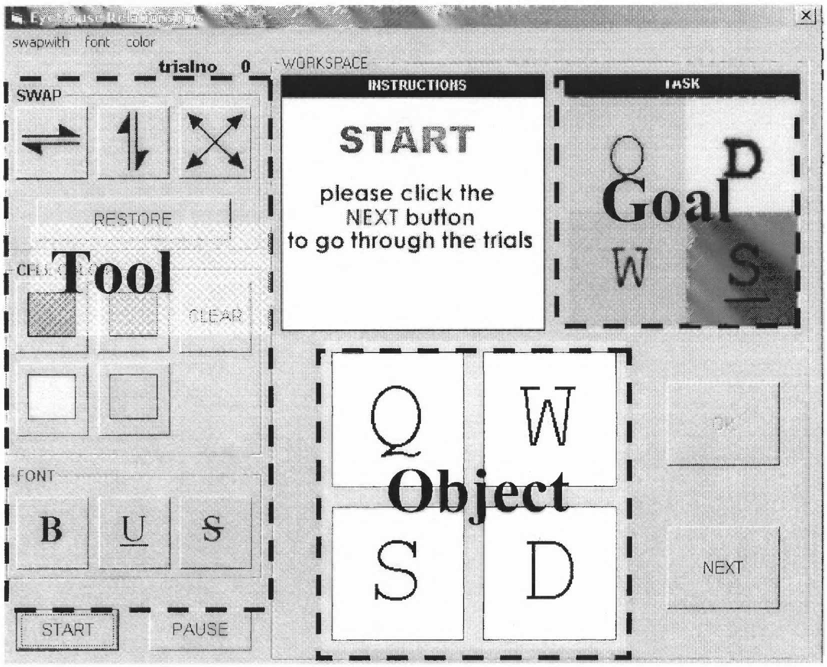


Figure 4.4 The experimental interface.

a) The tool area. This area of the interface display consisted only of icons, which could be clicked for imparting the feature desired and required by the arrangement.

b) The object area. This area consisted of the objects whose states were to be manipulated to achieve the final arrangement given in the goal area.

c) The goal area. This area is constant from the beginning to the end of the trial. This is the final desired arrangement the user must impart to the objects to successfully accomplish the task.

Table 4.3 describes the functions of the tools and the other elements of the interface. Some of the features like, "OK", "Next" and "Start" were based on experimental requirements.

Table 4.3 Final Interface Elements And Their Functions

Button or Selection	**Description**
Bold	Converts the text in the selected cell to **bold** format
Underline	Converts the text in the selected cell to <u>underline</u> format
Strikethrough	Converts the text in the selected cell to ~~strikethrough~~ format
Red	Converts the cell color to red
Green	Converts the cell color to green
Yellow	Converts the cell color to yellow
Cyan	Converts the cell color to cyan
Swap horizontal	Switches the position of the selected cell with that on the left/right depending on the cell which is selected
Swap Vertical	Switches the position of the selected cell with that on the top/bottom depending on the cell which is selected
Swap diagonal	Switches the position of the selected cell with that diagonally opposite depending on the cell which is selected
Reset	Restores the cell positions to the initial state
Clear	Clears the cells of any colors
Start	Start the states/ experiments
OK	Subject should click this button when convinced about the exact matching of the given arrangement and the arrangement they have obtained through the use of the tools previously described.
Next	To proceed to the next trial. Will not be activated unless the subject correctly does the current one.
Pause/Resume	Pause any time between the end of one trial and before clicking next.

The goal representations for the different tasks were created in Photoshop ®. Depending on the experimental stages (explained in Section 4.7) the goal representations were imparted with various forms of the arrangement of the letters Q, W, S, and D. These arrangements were then used in the experiment as tasks. The tools used for accomplishing these goals (arrangement) are described in Table 4.3. A detailed description of the tools, results of their activation and the arrangements used in the experiment are contained in Appendix A.

4.4 Introducing The Independent Variables In The Design

One of the objectives of the study was to understand how the relationship between different eye and mouse movement measures change due to task interface relationships. This was discussed in Chapter 3. It was also seen in Chapter 2 that compatibility of operation sequence and tool arrangement can influence the sequence of tasks performed by the users as well as the task model developed by the users. Based on the above, the two independent variables used in the study were the tool arrangement (independent variable addressing display structure) and the task sequence compatibility (independent variable addressing task interface relationship).

4.4.1 Embedded Task Sequence And The Interfaces

The experimental test bed used for the study aimed at reflecting the difficulty of task sequences and their support by the interface features for smooth operation. In Chapter 2, examples of different task sequences in regular software interfaces were demonstrated. The difficulties due to these task sequences were outlined and the importance of this aspect for our study was explained. However, to test this using an experiment, it was important only to use features, which are relevant to interface features and task sequence.

Figure 4.4 showed the interface devised for the experiment. This interface was then manipulated for different visual features and embedded task sequences so that different levels of usability could be obtained. Although, the number of instances of the interface can be twelve in this case, the experiment was carried out with only four versions. A pilot study showed that position was a dominant feature and was always performed first by the user. As a result the task sequence was based on position as the first function. Two displays and two task sequences were used resulting in four different combinations. These combinations of display and task sequence are explained in the following sections.

The basis of using the display and the task sequence combination was motivated by the study of Sears (1993) and Tullis (1988). Although their work only investigated information presentation and optimal task sequences, they concluded that people prefer to work from top to bottom, be it reading text or performing operations. Shneiderman (1997) also came up with similar conclusions regarding the design of display-based interfaces. The notion of using the task sequence form top to bottom was employed to study the usability and the effect of this usability level on different eye and mouse movements of the users performing the tasks on the interface.

Before explaining the different interfaces, the terms used to define the relationship between task sequence requirement and the display structure require the following final definitions:

Compatibility: The functional relationship between the display structure and the embedded task sequence requirement. If the display structure or layout (top to bottom or bottom to top) supports a particular sequence then it is defined as compatible, if not, it is incompatible.

Tool arrangement: The display structure or the arrangement of the interface elements on the screen, which supports a particular operation. It can be top to bottom or left to right or any spatial sequence.

Now the different interfaces that were devised on the basis of these relationships are detailed showing both the structure and the sequence required to perform the task. They are.

1. Compatible from top:

Compatible from top uses a tool arrangement, which is consistent with the embedded task sequence. In this case the tool arrangement is from top to bottom with the position tool being on the top, followed by the color tools and then the format tools. The embedded task sequence is also in the same order as that of the layout of the display, that is the position tool being the first, then the color tool and then the formatting tools. See Figure 4.5 for details.

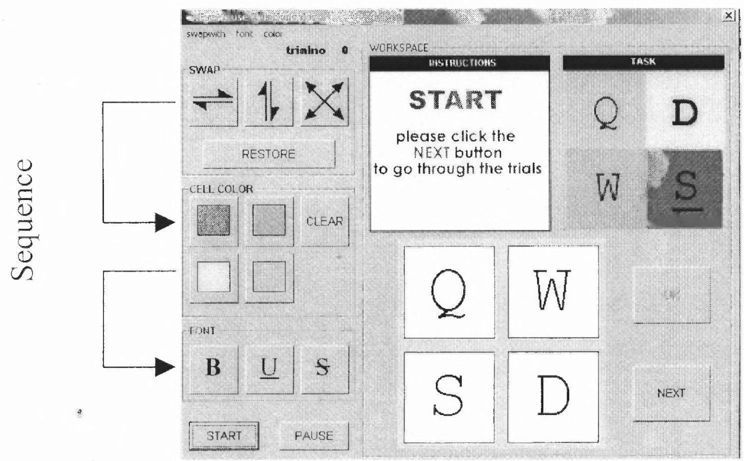


Figure 4.5 Compatible from top. (Embedded sequence: position→ color → format: display from top: position→color→format).

2. Compatible from bottom:

In this case the tool arrangement is from bottom to top with position being the lowest tool group, followed by the format and then the color tools. The task sequence embedded with the interface is also based on the same order from the bottom, which is position first, then format and then color as shown in Figure 4.6.

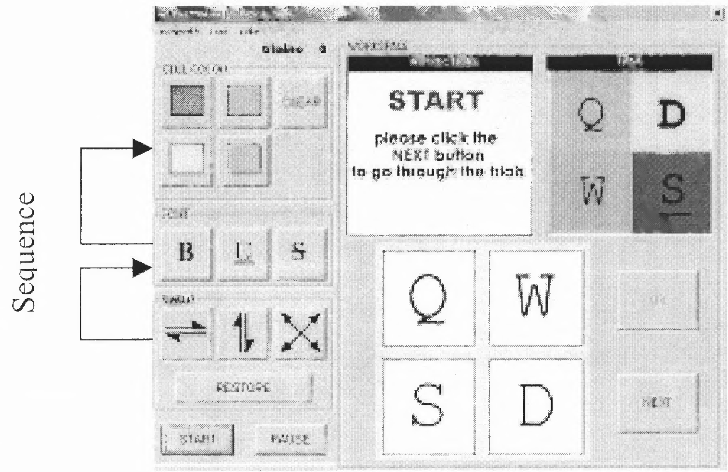


Figure 4.6 Compatible from bottom. (Embedded sequence: position→ format → color: display from bottom: position→ format → color).

3. Incompatible from top:

The incompatible form top case uses the same display as that of the compatible from top but a different embedded sequence in the interface, which is not congruent with the display structure of the tools. In this case the embedded task sequence is position, format, and then color as shown in Figure 4.7.

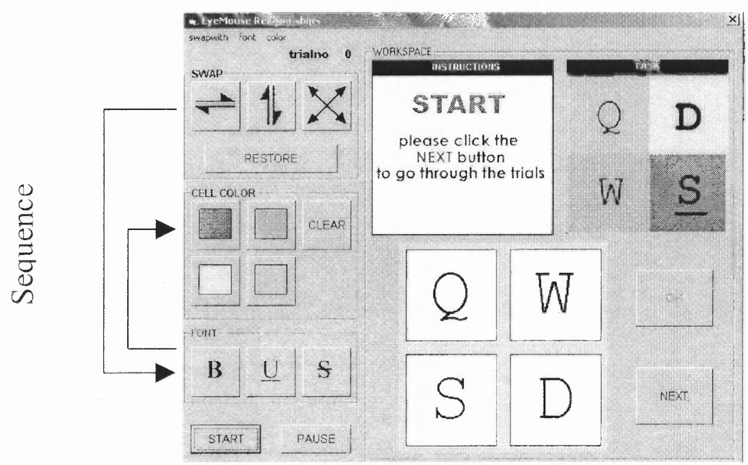


Figure 4.7 Incompatible from top. (Embedded sequence: position→ format →color: display from top: position→color→format).

4. Incompatible from bottom:

The display used in this case is the same as that for the compatible from bottom display but uses a different task sequence, which is not congruent with the display order form the bottom. In this case the sequence used is position, color, and then format, which is not congruent with the display layout, from the bottom as shown in Figure 4.8.

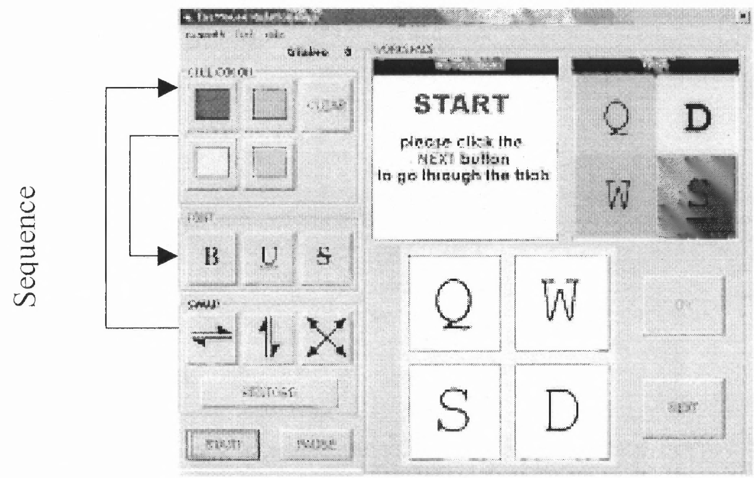


Figure 4.8 Incompatible from bottom. (Embedded sequence: position→ color →format: display from bottom: position→ format → color).

Hence, in this experiment, two display layouts had compatible task sequences whereas the other two were incompatible due to non-matching of tool arrangement and task sequence. This resulted in four groups with different levels of compatibility of task sequence requirement with the tool display (tool arrangement). It should be noted that the design principles were deliberately violated in order to observe the difference between groups with respect to the dependent variables. The basis of using two displays (from top and from bottom) was to observe any effect of the visual scanning; top down or bottom up on the performance.

On the basis of the above discussion the final experimental design is shown in Table 4.4 with the between groups design variables.

Table 4.4 Factorial Design For The Experiment

	Tool Arrangement 1	**Tool Arrangement 2**
Compatibility 1	*From top*– position, color, format Sequence (*compatible*) -position, color, format Subjects – 8 **Compatible from top group**	*From bottom*– position, format, color Sequence (*compatible*) - position, format, color Subjects – 8 **Compatible from bottom group**
Compatibility 2	*From top*– position, color, format Sequence (*incompatible*) -position, format, color Subjects – 8 **Incompatible from top group**	*From bottom* – position, format, color Sequence (*incompatible*) - position, color, format Subjects – 8 **Incompatible from bottom group**

The within group effect of phase of learning on the performance of the subjects will be considered in the next section based on the performance curves of the groups (Chapter5, Section 5.1.1) and the model for analysis of variance will be formulated on the basis of the final design addressing both the between group factors of Compatibility and Tool Arrangement and the within group effect of phase of learning.

The potential problem, which might be a reason for concern in this form of experimental design, is that, there might be an individual effect of a certain sequence. For example, if the compatibility is kept fixed and the tool arrangement is varied or if the tool arrangement is kept fixed and the compatibility is varied, then the existence of preferred sequence may rise. In this case, such confounds were assumed to be not present on the basis of the pilot study, which suggested that the most preferred sequence by the users even in case of unconstrained sequence (no priority in performing the features on the letters) was the position buttons first followed by the color or the format buttons. Hence the sequence was defined on the basis of position as first and then color or the format feature as the second or third features.

4.4.2 Dependent Variables

As per the research hypotheses three dependent variables were sought. These were

The efficiency of performance:

Standard performance efficiency measures are associated with the cost of performing the task. If the number of actions (clicks) required to complete the task are higher than required due to the compatibility of the relationship of interface display and the task requirement, then the usability of the interface can be assessed by the click efficiency of the users. The data required for obtaining the efficiency of performance is standard time data and the click or the mouse event data, which can provide the excess number of clicks done by the users and hence the cost associated with the usability.

The motor response of the subjects:

Mouse movements reflect the motor performance of the users on an interface. Any disruption in task performance due to usability violations may cause the users to perform the task inefficiently with more movements and clicks than necessary. The usability of the graphical user interface arising from compatibility of task sequence requirement and display structure can be assessed by studying the mouse traversal during task performance. It is expected that an increase in mouse traversal rate will indicate efficient performance due to faster operation and task execution through access of tools.

The data required for this is the mouse movement data reflecting the speed of motor response and the operational efficiency attained by the subjects.

The search efficiency:

Since users rely on eye movements to perform the tasks by perceiving user interface elements, eye movements should reflect the performance of the users and the usability levels of the interfaces associated with the different task sequence requirements and display relationships. If the compatibility of the task sequence and the display is high then the search efficiency will be high, while a lower degree of compatibility will affect this search efficiency and increase the number of visits made by the users to the different areas of interest. Studying the eye movement data can provide the number of visits required and also the processing time per visit and therefore an estimate of the search efficiency during task performance.

To obtain the data an apparatus is required which is the subject of the next section.

4.5 Apparatus

The apparatus is discussed in two parts. First there is a description of all the equipment and their specifications. Then the ideal setup for the experiment is explained. The equipments used were all obtained from the Vision Research Laboratory of the Biomedical Engineering department and the Human Factors and Safety Laboratory of the Industrial Engineering Department. The whole setup was done in the Vision Research Laboratory.

4.5.1 Eye Tracking System

A RK 426PCI corneal reflection Eye Tracking system manufactured by ISCAN Inc. of Massachusetts was used in the study. The overall system is depicted in Figure 4.9. The system consists of a data acquisition card (RK620 PC) and a pupil/corneal reflection tracking system (RK726 PC) (see Figure 4.9). The important part is the head mounted eye camera and the scene camera. The dichroic mirror and the cameras send two signals two the eye and the scene monitors through the cards (see Figure 4.8). The software used to control the pupil/corneal reflection tracking system is also produced by ISCAN and is known as the Eye Movement Data Acquisition software.

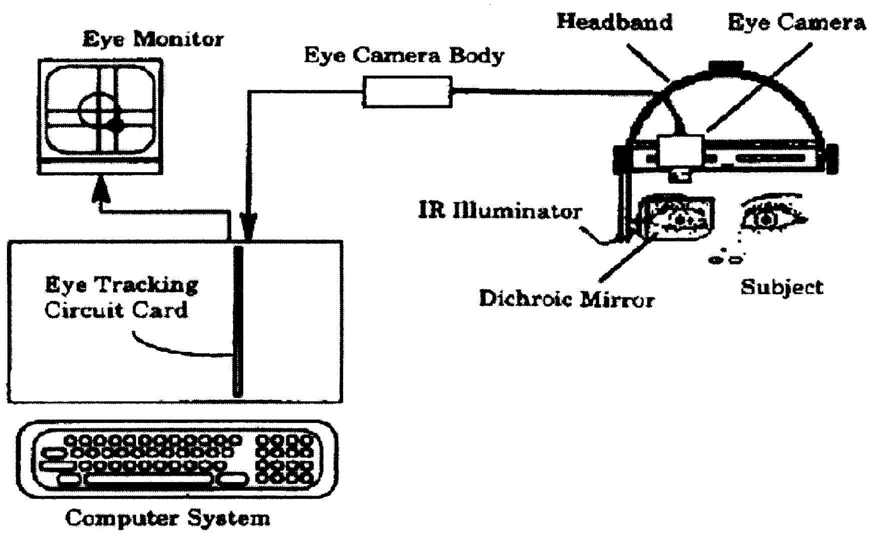


Figure 4.9 ISCAN Eye tracking system (courtesy ISCAN).

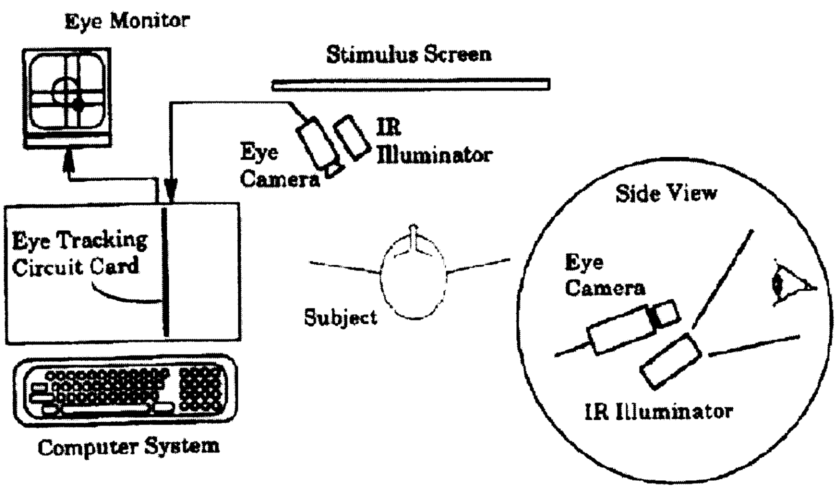


Figure 4.10 Desired Subject position and mirror functions (courtesy ISCAN).

The other software, which tracks the line of sight and plane of intersection, is the software for the Headhunter System for tracking head movements. However, the facilities precluded the use of the Head Hunter System. A Windows 98 PC was used in this case with the computer running in the dos mode. The software showed no awkward results in terms of proper running.

4.5.2 Other Equipments And Accessories

1. Video recorders:

An industrial grade VCR was used for the experiment. The VCR was of RCA make and capable of multiple functionalities including frame search, indexing, frame advance, still, timer and time indexing.

2. Computers for subject:

A PC with Windows 98 operating system and running Visual Basic was used for the subjects to perform the tasks. A Pentium 4 processor with 800-megahertz speed was used.

3. Chinrest:

This was developed in the Robotics Laboratory of the Industrial and Manufacturing Engineering Department. It had an adjustable stand for accommodating different chin heights. The surface on which the chin rested was made of polythene material for providing a soft surface. This surface was cleansed with solution before each experiment for hygiene purposes. The chin rest had two different contours, one convex and the other concave to accommodate subjects' preferences. The alignment was slightly at an angle for ergonomic reasons so that the edge of the chin rest does not hurt the user skin at the bottom of the chin. The schematic diagram of the chin rest is shown in Figure 4.11.

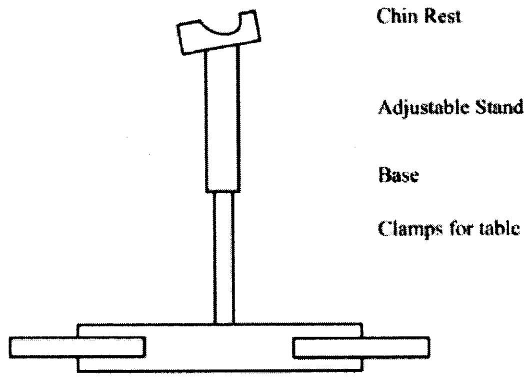
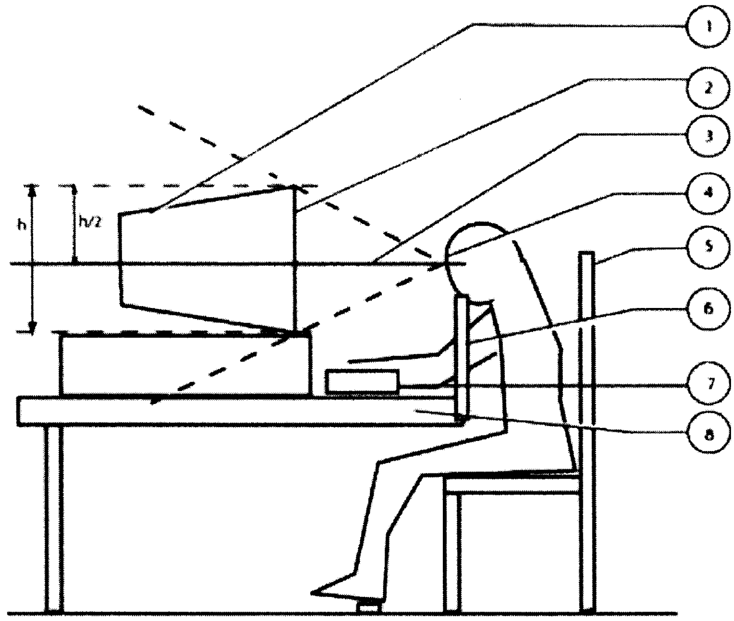


Figure 4.11 Chin rest assembly designed for subjects.

4.5.3 Room Arrangements And Setup

The room setup and the layout for the experiment is shown in Figures 4.12 and 4.13. Figure 4.12 shows the relative positions of the subject and equipment while Figure 4.13 shows the equipment locations and arrangements with layout. Some important considerations have been highlighted below. The lighting conditions for the room were dark to improve the signal to noise ratio of the eye tracker as fluorescent light can potentially interfere. The scene monitor should preferably be connected to a videocassette recorder, which may be stationed underneath the table on which the monitors rest.

The partitions should be black for absorbing as much ambient light as possible. The target to be studied was well illuminated for proper reception by the scene camera. Subjects should preferably use a chin rest for low-resolution (max sampling at 60 hz) experiments. The provision for a bite bar is necessary experiments, which demand high-resolution (minimum sampling rate of 120 to 240 Hz) data.



Legend

1. Monitor/area of interest for the subject
2. Screen plane orthogonal to the line of sight of the subject and through the center of the screen for a true picture to be obtained on the scene monitor
3. Line of sight having zero degree visual angle with the monitor surface at the center of the screen.
4. Subject eye position fixed by use of chin rest. Calibration and adjustment to be done for every subject due to anthropometrical differences
5. Chair (fixed or adjustable according to experiment requirements).
6. Chin-rest (preferably adjustable) provision for a bite bar is recommended
7. Key board or any other input device as required by the experiment
8. Fixed table

Figure 4.12 Desired position of subject with respect to computer screen.

The camera, if required for experiments, should be placed at 30-45 degree angle with the line of sight of the subject and at a distance of 4 ft - 5 ft from the monitor adjusted for focus. Subjects should be calibrated for eye as well as position from the area of interest/target area with respect to the appropriate scene on the scene monitor. The room should be without windows and properly ventilated to reduce the entry of external sources of light. This is also necessary in eye movement studies where proximal viewing has to be inhibited. Provision for a tape recorder is optional and may be necessitated according to the requirements.

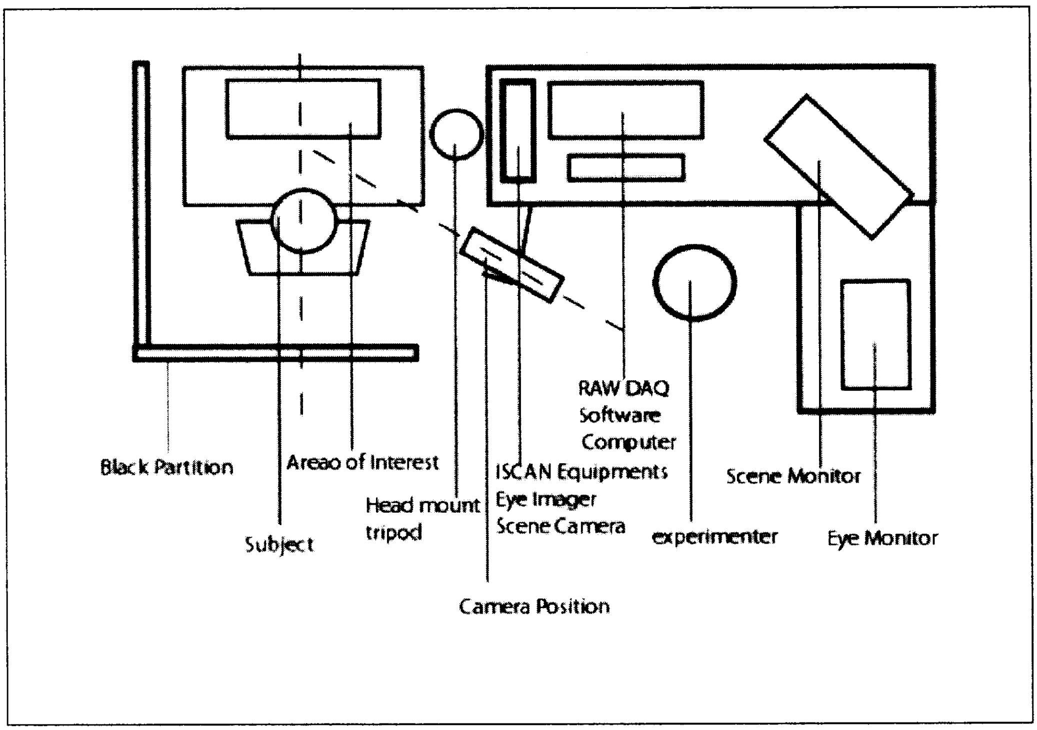


Figure 4.13 Layout and location of eye tracking equipments.

Two PCs with Windows 98 operating system and one of them with Microsoft Visual Basic® was used in the experiment. The first one had the necessary software for running the eye registration equipment and will be known as the Experimenter experiment and will be known as the Subject workstation. The actual photograph of the laboratory setting is given in Appendix A.

4.6 Subjects

All subjects were recruited from the New Jersey Institute of Technology staff and student population and appropriate authorization for human subjects in experiments was obtained (Appendix B.1). Subjects were asked to read and sign an informed consent form (Appendix B.2) and provide information about software usage experience through a Background Survey (Appendix B.3) before the experiment. Subjects were given an incentive for completing the experiment in the form of financial compensation.

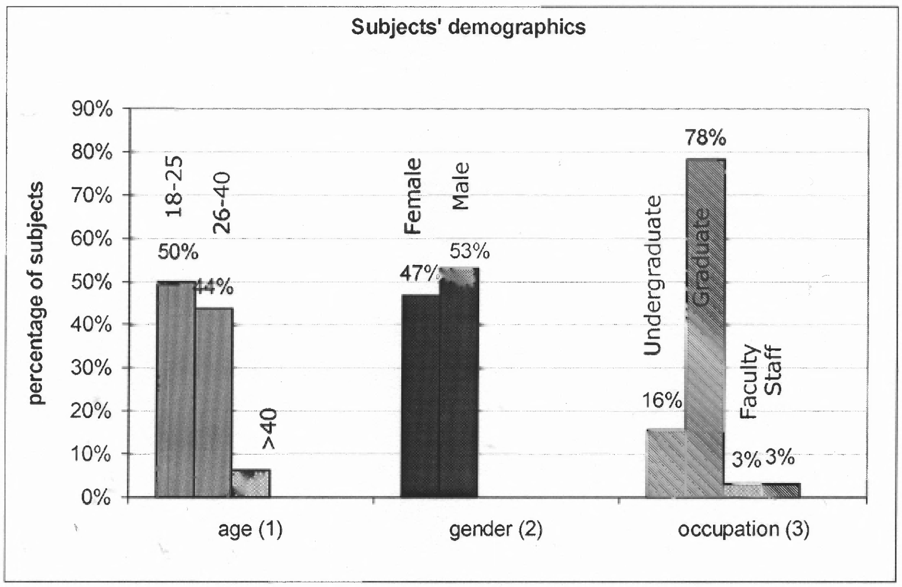


Figure 4.14 Subjects' demographics expressed as percentage of the population of 32 subjects for the experiment.

15 females and 17 males participated in the study. They were equally distributed in the different groups. Subject demographics revealed the fact that the population was quite savvy with the use of computers. 50% of the subjects were 18 to 25 years of age, 43.8% were 25 to 40 years of age and 6.3 % were more than 40 years of age. 15.69% were undergraduate students, 78.19% were graduate students and 6.38% were faculty and other staff (see Figure 4.14).

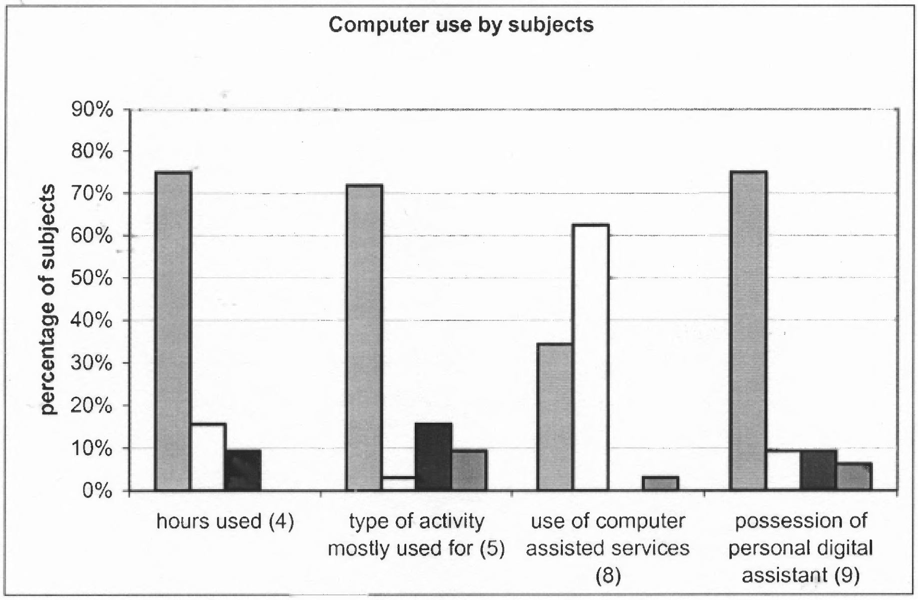


Figure 4.15 Subjects' computer usage expressed as percentage of the population of 32 subjects for the experiment

75% of the subjects used computers regularly for at least more than four hrs/day, 15.6% more than two hrs /day and the rest used at least three to four times per week. 71.9% of the subjects used computers primarily for work. 3.1% mentioned that they used it for entertainment, 15.6%used it for communication purposes, and 9.4% of the subjects use computers for online learning (see Figure 4.15 for details). (numbers in parentheses represent question number from the questionnaire).

An overwhelming 96.9 % of the subjects were familiar with word processing software, 90.6% with spreadsheets, and 90.6% with email facilities. 100% encountered the Internet while 50% regularly used some different types of software for work. 34.4% of the subjects used computer assisted services, like the ATM or the ticket vending machines all the time while 62.5% used them frequently. 75% of the subjects had some kind of personal digital assistant like a cell phone or palm pilot, while 18.8% of them had 2 or more (see Figure 4.16).

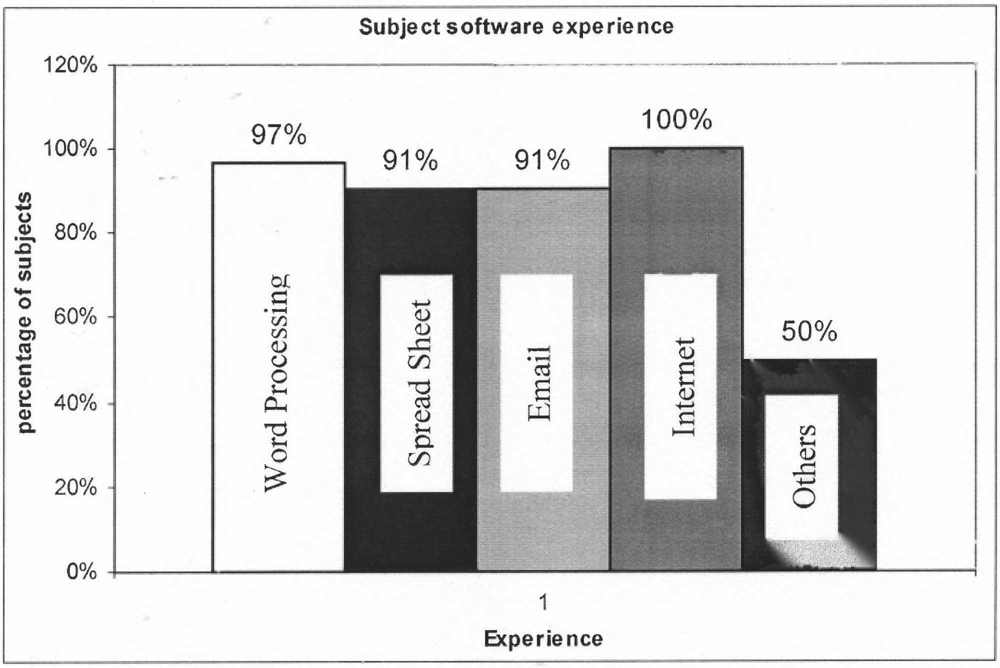


Figure 4.16 Subjects' software experience expressed as percentage of the population of 32 subjects for the experiment.

32 subjects (8 in each group) performed all experimental tasks. Visual acuity and experience with computers in different backgrounds was considered more important than age for the study. Potential subjects were prescreened for an uncorrected vision. This was based on information given by the subjects on their use of corrective lenses. Subjects with corrective lenses produce additional surface reflections, which interfere with the eye

tracker's functioning. Subjects with corrected vision and using glasses or contact lenses were not allowed in the experiment.

4.7 Procedure

The experimental procedure was designed with the following considerations. In Chapter 3 theoretical assumptions regarding the interaction of subjects while working on a user interface were discussed. The task procedure had to be designed keeping in mind various factors that influence the performance of the subjects. Our main objective was to understand how the subjects adjusted to the experimentally designed sequence of the interface through task performance and the corresponding changes in the eye and mouse movement measures. Extraneous factors that could influence the performance were

- The location memory of the individuals.
- The speed of performance.
- The understanding of the individual functions of the elements.

Using two sets of learning tasks at the beginning of the experiment could minimize all these factors. The first set used consisted of tasks using only one particular group of features and hence the subjects did not have to understand the complete experimental sequence. The second set involved only two groups of features in combination. This also did not expose the complete sequence to the subjects as most of the subjects were expected to do the positioning operation first followed by the other operations from color or font. The choice of this set was based on a pilot study involving 5 subjects, which justified the fact that all the users preferred to do the positioning operation first followed by the other operations. The complete experimental procedure is explained in the following steps.

1. The subjects were first given a consent form and questionnaire to be filled out. The questionnaire accounted for the subjects' background and experience with computer systems and other interfaces of daily use, like cell phones, ATMs, ticket machines etc (see Section 4.6).
2. The elements of the interface and how each icon or tool functions were then explained to the subjects.
3. A break was given to the subjects to familiarize themselves with interface details and the procedure of the experiment as outlined in the consent form. During this period the experimenter set up the equipment for eye movement registration.
4. The eye movement data acquisition system was started and calibrated for subjects using a five-point calibration.
5. The subjects then went through two sets of tasks (12 each). The first set required only one single feature to be manipulated. The second set required two features to be manipulated in sequence. These were the two practice sets.
6. A break was allowed at this point only on the consent of the subject but it was requested that go through the complete experiment in one sitting.
7. Subjects then went through the experimental set of tasks, which consisted of the complete task sequence. The subjects performed 16 tasks in the experimental set.
8. The subjects were then compensated and debriefed on the objectives of the study and use of data. They were also allowed to observe the video recording.

The complete experimental flow chart is depicted in Figure 4.17.

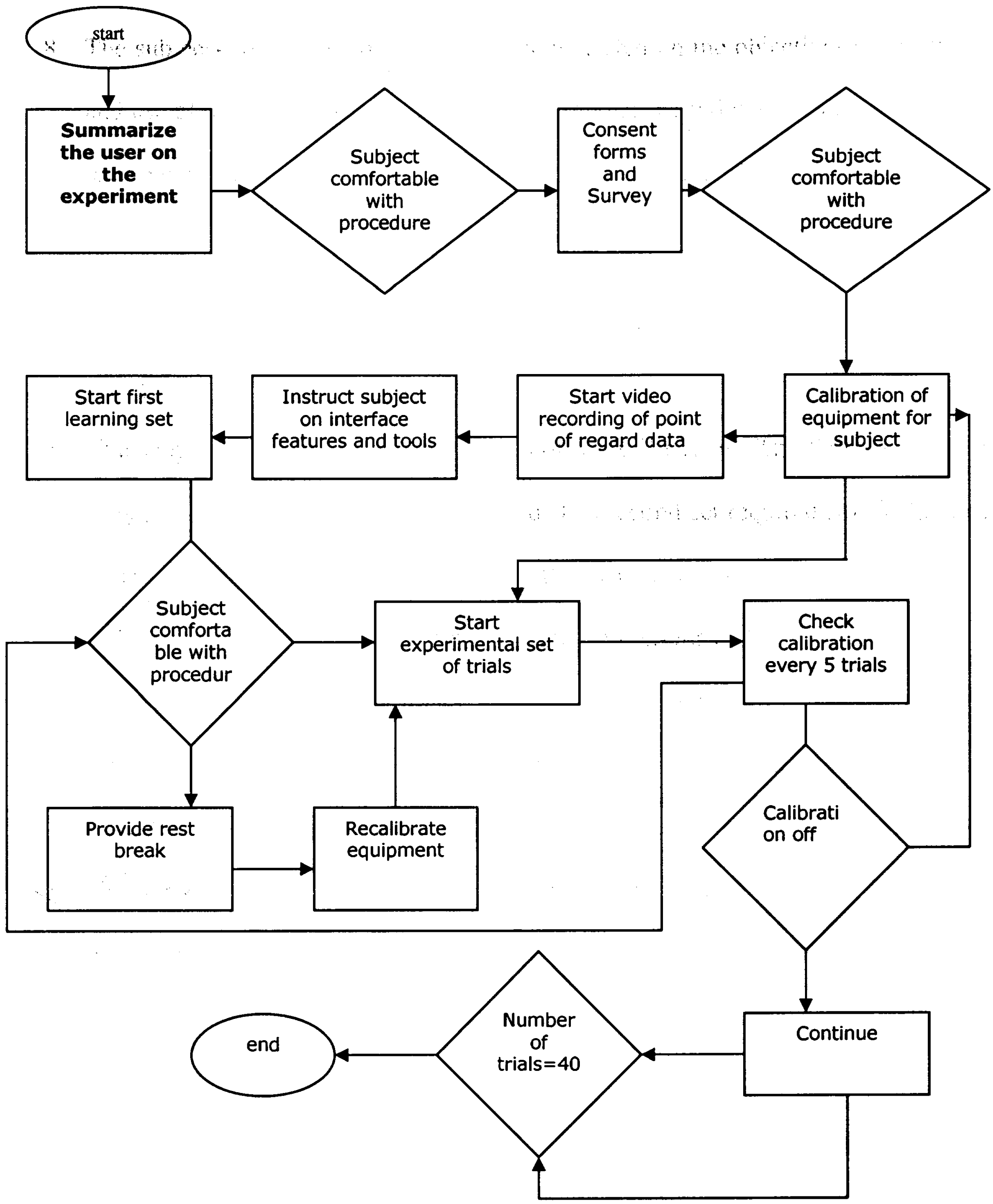


Figure 4.17 Flow chart of the experiment.

4.8 Data Collection and Measures

The data collected during the experiment consisted of the mouse movement data from the experiment interface and the eye movement data form the interlaced video recording of the experimental session. The raw data was then manipulated to obtain derived measures as explained in the following sections.

4.8.1 Handling Raw Data Files

The raw data was collected from the following sources:

a. Mouse events based on interface codes and actions on the interface elements/widgets, which were namely the tools and the objects.

b. The mouse movement coordinates.

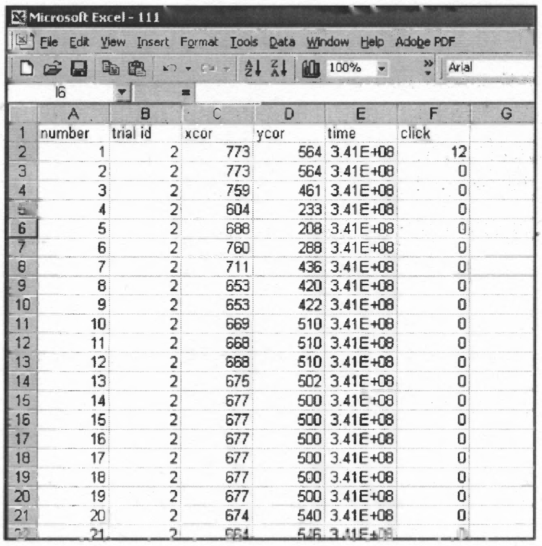
c. Time of performance in terms of the sampling rate of the coordinates, which was kept at 10 hertz. This was based on experimental data of the fastest possible movement with mouse. The sampling rate was kept at 100 ms in order to catch every movement made by the user.

d. Video recording of the experimental screen with eye movement point of regard was captured. Eye movements were recorded at 60 hertz. According to Yarbus (1967) eyes take at least 100 milliseconds in order to fixate and encode stimuli for appropriate task performance, hence a 16.67 milliseconds interval was chosen to be appropriate in order to understand users movement and gazes in the different areas of the screen.

One of the objectives was to study the behavior of eye and mouse movement and their relationships. Established parameters were used in cases where available. However, for an eye-mouse relationship, data measures had to be formulated on the basis of video observations. The dependent variables studied came from three sources; a) mouse movement only b) eye movement only and c) relation between eye and mouse movement.

Each of these derived measures is described separately. First the method of calculation is described stating the data processing techniques and the data used. Second their significance towards usability is mentioned.

The first raw data set consisted of the mouse movement data. The sample raw data sheet is given in Figure 4.18 below. The length of the file depends upon the time taken by the subject to complete the trial. Each trial had one raw data file thereby generating 16 raw data files for each subject relevant to the analysis.



	A	B	C	D	E	F	G
1	number	trial id	xcor	ycor	time	click	
2	1	2	773	564	3.41E+08	12	
3	2	2	773	564	3.41E+08	0	
4	3	2	759	461	3.41E+08	0	
5	4	2	604	233	3.41E+08	0	
6	5	2	688	208	3.41E+08	0	
7	6	2	760	288	3.41E+08	0	
8	7	2	711	436	3.41E+08	0	
9	8	2	653	420	3.41E+08	0	
10	9	2	653	422	3.41E+08	0	
11	10	2	669	510	3.41E+08	0	
12	11	2	668	510	3.41E+08	0	
13	12	2	668	510	3.41E+08	0	
14	13	2	675	502	3.41E+08	0	
15	14	2	677	500	3.41E+08	0	
16	15	2	677	500	3.41E+08	0	
17	16	2	677	500	3.41E+08	0	
18	17	2	677	500	3.41E+08	0	
19	18	2	677	500	3.41E+08	0	
20	19	2	677	500	3.41E+08	0	
21	20	2	674	540	3.41E+08	0	
22	21	2	[illegible]	[illegible]	[illegible]	[illegible]	

Figure 4.18: Mouse movement raw data file.

4.8.2 Measures Based on Mouse Movement Data

The software for the experimental interface was coded to capture mouse events (clicks and movements) and coordinate data. This data was stored in a log file separately and sampled at 10 hertz. The measures of total duration and efficiency were derived from the mouse movement data as an indicator of task performance, since they are generally used in usability studies. (Please refer to Chapter 2).

Click efficiency (E): For each task there were a minimum number of actions that could be used to accomplish it. However the users either used minimum actions or used more according to the errors they face or the strategy they choose. The efficiency was based on the formula

$$E= [\text{Number of actions required } (n_{ideal}) / \text{ Number of actions used } (a_{ctual})]$$

Expressed as a ratio or percentage

The definition of efficiency in this case is affected by four different sources. These are

1. Errors due to misapplication of tool.
2. Errors due to embedded task sequence.
3. Errors due to omission of a feature.
4. Excess clicks due to strategy.

The assumption is that all the errors except the errors due to embedded task sequence, which is due to treatment, are uniformly distributed. Errors due to the embedded task sequence which influence the eye and mouse movement relationships are not uniformly distributed due to the fact that users were specifically instructed to adjust their strategy during the operation sequence.

The efficiency basically reflects the errors due to the compatibility of the task sequence with the tool arrangement and hence it is an indicator of subject performance. The lower the efficiency, the higher the number of actions used for the task and lower is the usability of the interface. This is due to the fact that subjects commit mistakes due to the inconsistency of the task interface relationship. This results in the lower usability of the interface arising from the incongruence of task and interface features.

The pseudocode used for Visual Basic to obtain the efficiency and the mouse traversal are given in Figure 4.19 and 4.20 as shown below.

```
Input raw data file (xcoordinate, ycoordinate, timecode, clicks)
If end of file go to next input file
Else
For start to EOF
T-start = time code when click="next"
T-end= time code when click="OK"
Total time of trials =T-start- T-end

If Click not equal to 0
Sum of clicks= Sum of clicks + Click
Else
Go to next

Get ideal number of click for trials
Efficiency = Ideal/actual

Print# Total duration
Print # efficiency
```

Figure 4.19 Pseudo code for Visual Basic for obtaining duration of trials and mouse traversal.

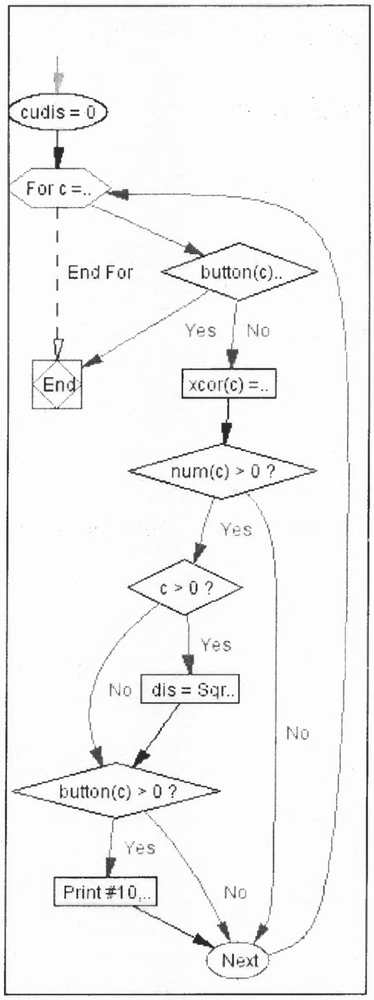


Figure 4.20 Flow chart of VB code for obtaining mouse traversal.

Mouse Distance Traversed/unit time (mouse traversal rate: MT)

$MT_i = M_i/t_i$ .... where, M = Mouse traversal in task i

and t = time to complete task i

Unit: pixels/second

This measure reflects the speed at which the users are performing the task as well as how efficient they are in accessing the tools. Larger traversal indicates efficient movement and performance. Mouse movements depend upon various factors. As discussed in chapter 2, mouse movements mostly corroborate either to the events during the task performance or to the indecision on part of the users when they are not able to find the particular icon for the task or subtask. The number of mouse clicks has already been considered in the efficiency measure. Here movement in terms of distance traversed is considered. The lower the mouse traversal per unit time, the more time is required by the users to perform a certain action. Users may also do more clicks in less time

4.8.4 Measures Based on Eye Movement Data

The second raw data set consisted of the eye movement data. The dispersion threshold is either measured in angles of visual arc or in pixels traversed by point of regard data. This is the amount of variation in the coordinates of the point of regard, which will associate a given range of points to a saccade or a fixation. The total number of fixations along with the fixation duration is taken as the gaze at the particular area of interest. Based on the defined areas of interest and the visual angle of these areas, the average dispersion threshold was calculated based on 200 saccades obtained from video observation and analysis. This value was then used for the algorithm as the dispersion threshold based on transformation duly applied for normalization of the coordinates for all subjects. The average distance of the subjects from the computer screen was about 19.81 inches with a SD = 1.13 inches as shown in Table 4.5. The dispersion threshold was calculated using the formula visual angle=3438X H/D , where D (distance) was taken as 20 inches and average saccade length was 100 pixels.

Table 4.5 Average Distance (D in inches) From Computer Screen For Subjects

Sub No	Compatible from top	Compatible from bottom	Incompatible from top	Incompatible from bottom	overall
1	20.83	19.28	20.72	20.69	
2	19.16	19.79	18.00	21.06	
3	21.12	18.23	21.07	19.83	
4	18.66	19.14	20.34	20.62	
5	20.36	20.42	19.17	19.61	
6	18.77	20.35	21.87	21.59	
7	18.22	19.91	20.12	20.97	
8	19.94	18.00	18.02	18.15	
					mean/stdv
mean distance	**19.63**	**19.39**	**19.91**	**20.32**	**19.81**
St.dv.	**1.07**	**0.90**	**1.40**	**1.08**	**1.13**

4.8.4.1 Areas of Interest (AOI)

Defining areas of interest (AOIs) is an important aspect in eye movement studies. However, in this case the AOIs were already pre identified as the tool, object and goal areas. This is particularly important in case of usability studies where the areas of interest are based on contextual aspects. Researchers identify these areas of interest based on predicted task performance and attention to the areas of the interface display. Using tool, object and goal areas sets a general paradigm for identifying areas of interest in an interface display

Based on the study of different task paradigms, it was concluded that tools, goals and objects were the main elements of a task. If the AOIs are associated with these task paradigms then most of the users' attention should be focused in these three areas, while the rest of the interface should have a minimum eye movements registered. Hence, the metrics derived on this basis will be task dependent but not task specific.

4.8.4.2 Procedure for Obtaining Eye Movement Data

Although the eye movement point of regard coordinates were recorded, there were inherent difficulties with the analysis of the point of regard coordinates due to equipment restrictions. As a result the eye movement data was obtained through the analysis of the point of regard video.

Figure 4.20 shows the eye point of regard and the interface interlaced on the video. This calibrated position of the eye point of regard was tracked throughout the complete experiment and the data based on the eye movement were obtained.

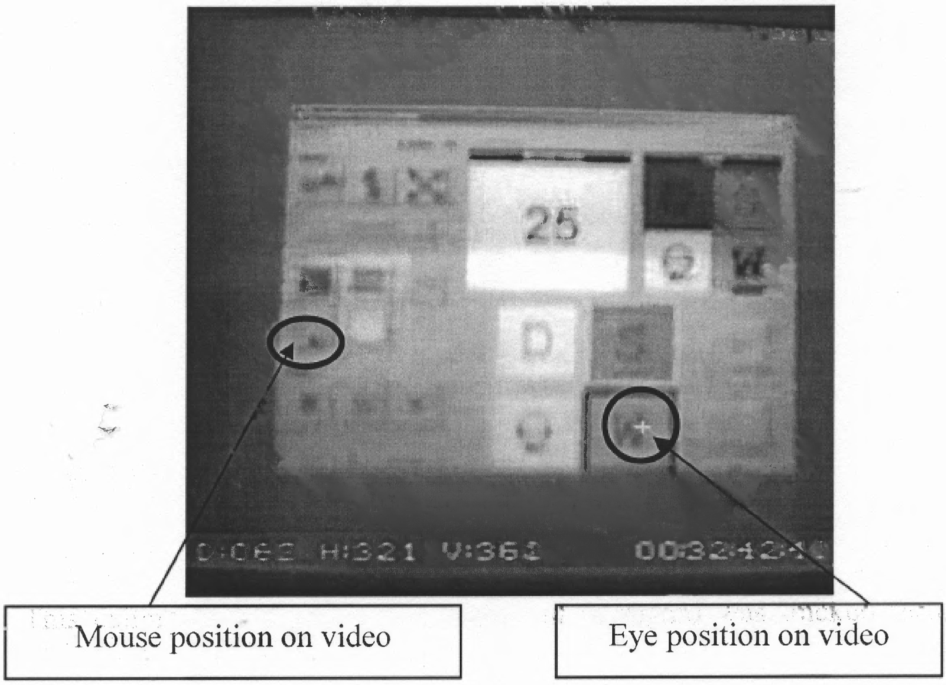


Figure 4.21: Video capture showing eye and mouse positions used for obtaining eye movement data.(Here the eye point of regard is on the object area)

4.8.4.3 Measures on the Basis of Eye Movement Data

During the course of the task the eye and the mouse visit different areas of interest as described earlier. The number of visits represents the total number of transitions of the eye from any other area to the specified area of interest (tool, goal or object). For example in the case of number of visits to the tool area, the total number of visits to this area by the eye will be calculated on the basis of the number of transitions the eye made there during the task performance.

Total number of eye visits to object and tool areas per click (V):

This represents the amount of confusion that existed at the initial stage of the task. It is to be noted that the number of eye visits depends upon the particular subject. Hence, obtaining results simply on the basis of group differences may not be the true picture of the process. Analysis of the results needs to consider the learning as well as individual differences that may exist in terms of eye movement patters used during the experiment.

The total number of visits (V) here is calculated as

[Number of visits in the goal area + number of visits in the tool area + number of visits in the object area for a particular trial]

Hence if V_g is number of visits in the goal area, V_t is number of visits in tool area and V_o is the number of visits in the object area for a particular trial, then the total number of visits for this trial is given by $V= V_g + V_t +V_o$.

Average processing time per visit (tv):

If the total time required to complete a trial is T and the number of visits during the trial is V then the average processing time per visit is given by tv =V/T. The reason this is called average is due to the fact that amount of time spent during each visit within the particular trial may not be the same and hence average time is used in this case.

From the literature review on eye movement characterization, it may be apprehended that there is a potential of loss of valuable data due to assimilating both saccades as well fixations in the measure of average processing time per visit. However, a closer look will reveal the fact that such kind of accuracy is not needed for the current study. In this case only time spent in the general areas are considered rather than the individual tools. Hence intra area saccades or movements are not important or can be assumed to be a small fraction of the total time the users spend during the visits. It is also a fractional time of the total task time. Furthermore, it can also be argued that scans inside the particular area are related to confusion arising from the inability to understand the choice of tool or object. This can be linked to greater time involved in the processing in the particular area ultimately resulting in inefficient search during performance.

Some of the other attributes, which were used to understand the subject behavior and the results obtained on the basis of these two measures, were:

Ratio of eye visits in the object area to ratio of eye visits to tool area (ETO): This ratio is defined as

ETO= number of eye visits in the object area / Number of eye visits to tool area

and it represents the difficulty of the user in executing actions in the tool area. If ETO is >1 then it represents difficulty on part of the user to execute actions in the tool area. The minimum value of ETO depends upon the familiarity of the user with the interface. A ratio of 1 can be considered as acceptable since the user is visiting the area for carrying out an action by the mouse (click). A higher ratio indicates that the user is facing difficulty in associating the task with the tools and thereby moving back and forth between the tool area and other areas of interest related to the task.

Only the object and tool areas are considered here while the goal area is not. All the measures devised in this section are for estimating the usability differences for this particular task. In case of other tasks or interfaces, similar ratios may be devised on the basis of the concept behind the derivation of these ratios. However, the theoretical basis of associating areas of interest to task performance will remain the same.

Percentage Dwell times in areas of interest: Three eye movement measures were derived on the basis of associating the areas of interest to task. It is believed that dwell times in the respective areas of interest can reflect the attention devoted to the elements of task performance and differences due to usability levels will be reflected in these measures. The measures are:

a) Percentage dwell time in tool area (PDT): Percentage dwell time in the tool area is referred to as the ratio of time the eye dwelled on the tool area to the total dwell time.

[PDT= dwell time in tool area/total dwell time] x 100 %

b) Percentage dwell time in object area (PDO): Percentage dwell time in the object area is referred to as the ratio of time the eye dwelled on the object area to the total dwell time. It represents the attention given by the subject to the object area of the interface.

[PDO = dwell time in object area/total dwell time] x 100 %

c) Percentage dwell time in goal area (PDG): Percentage dwell time in the goal area is referred to as the ratio of time the eye dwelled on the goal area to the total dwell time. It represents the attention given by the subject to the goal area of the interface.

[PDG = dwell time in object area/total dwell time] x 100 %

4.9 Summary

The next chapter tests all the relevant research hypotheses as mentioned in Chapter 3. Table 4.6 shows the research hypotheses, the dependent variables of interest and the measures used to study them.

Table 4.6 Research Hypotheses, Dependent Variables Of Interest And Measures

Research Hypotheses	Dependent Variable of Interest	Measure
HA	Performance	Click Efficiency (E)
HB	Motor Response	Mouse Traversal Rate (MT)
HC	Search efficiency	Number of Eye Visits (V)
		Average Processing time per visit (tv)

As a logical step towards the next objective of finding evidence to substantiate the research hypotheses, a set of experimental hypotheses is formulated and tested for differences of compatibility, tool arrangement and learning by the users during task performance. This not only gives us the sufficient information about the usability of the interface in terms of performance, but also in terms of how learning affects the assessment of usability and the effect of learning on the measures obtained from eye and mouse movements.

CHAPTER 5

EXPERIMENTAL RESULTS AND ANALYSIS

5.1 Introduction

As discussed in Chapters 2 and 3, learning of the task sequence requirement by the subjects in the different groups was considered to have a major influence on the estimation of usability levels. This is due to the fact that the processes (performance, mouse traversal and eye movements) from which the measures were derived can be affected by learning. The literature review also supported the fact that the measures obtained from mouse movements (Smith *et. al*, 2000), eye movements (Goldberg *et. al.*, 2002), and regular performance measures are sensitive to learning during exploratory behavior observed mostly in human computer tasks (Carroll *et. al.,* 1988). The Identification of this exploratory phase of learning is considered first.

The primary measures on which the evidence for the research hypotheses are sought are, click efficiency, mouse traversal per unit time, number of eye visits to the different areas of interest, and processing time during each visit. A repeated measures analysis of variance is used in this case to understand the interaction of phases of learning with the between group factors of compatibility and tool arrangement. The experimental hypotheses related to efficiency and mouse movement data are formulated and are tested with the same repeated measures ANOVA model (Section 5.1.2). This provides an understanding of how the eye and mouse movements were influenced by the compatibility of task sequence requirement and tool arrangement relationships and may provide the necessary evidence required to test the research hypotheses HA, HB and HC.

Their relationship to general performance measure of efficiency is also assessed. The overall summary of the sections in this chapter is shown in Figure 5.1. The block arrows represent the process by which the analysis of the results provided evidence for the research hypotheses and corresponding development of the systemic-structural approach to the study of human computer tasks and usability of graphical interfaces.

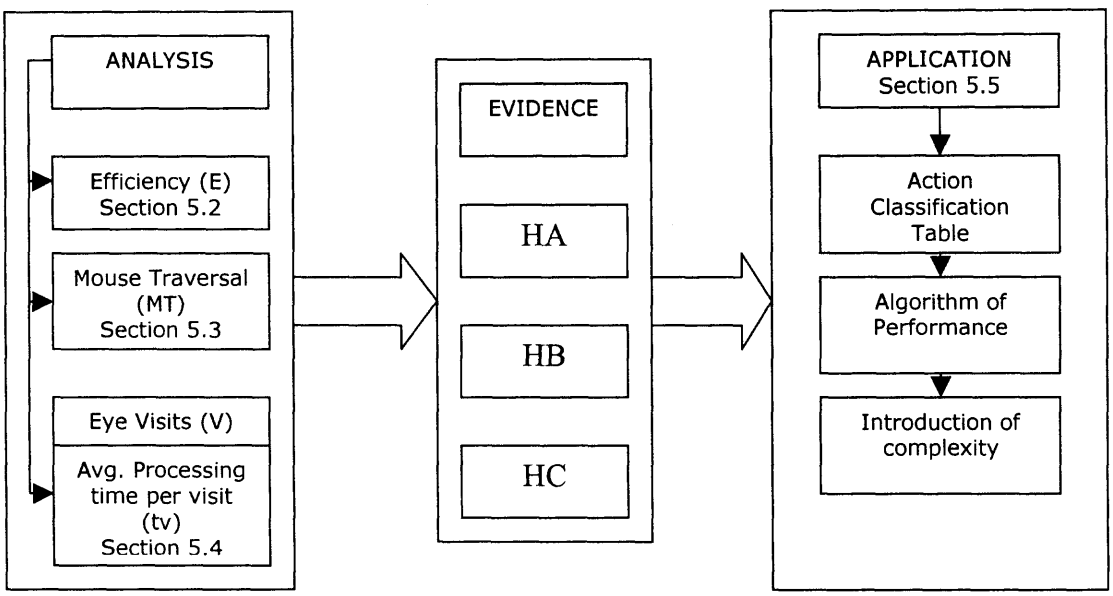


Figure 5.1 Analysis of experimental results for evidence of HA, HB and HC and the application of the findings based on eye and mouse movements.

5.1.1 Identifying The Phases Of Learning

For identifying the phases of learning, individual subjects' efficiency of performance was observed using a learning curve. A moving average efficiency using five consecutive trials were used for the power curve fits. The moving average was used to smooth out the effects of inter trial differences in efficiency. This improvement in performance over a course of trials can be estimated by a moving average efficiency (MAE) using a window of w trials. Hence if N is the total number of trials performed by the subject then the moving average for each subject in any group is given by:

$$MAE_k = \frac{\sum_{i=k}^{k+w} \lambda_i}{w} \quad where, (k+w) \leq N$$

where,

MAE= moving average efficiency
w=number of trials included in the moving average
k=number indicating the moving average
N= number of trials

here $w = 5$ and $N = 16$ in case of this experiment, hence, *k=1, 2, 3.... 12*

The power curve fits for the groups (see Figure 5.2) show that initially the groups struggled to understand the sequence, but finally their familiarity with the operation sequence increased and resulted in no perceivable differences. Based on this, the first five trials were considered as the exploratory learning phase (learning of task by exploratory behavior) and the final five trials are considered as the post-learning phase.

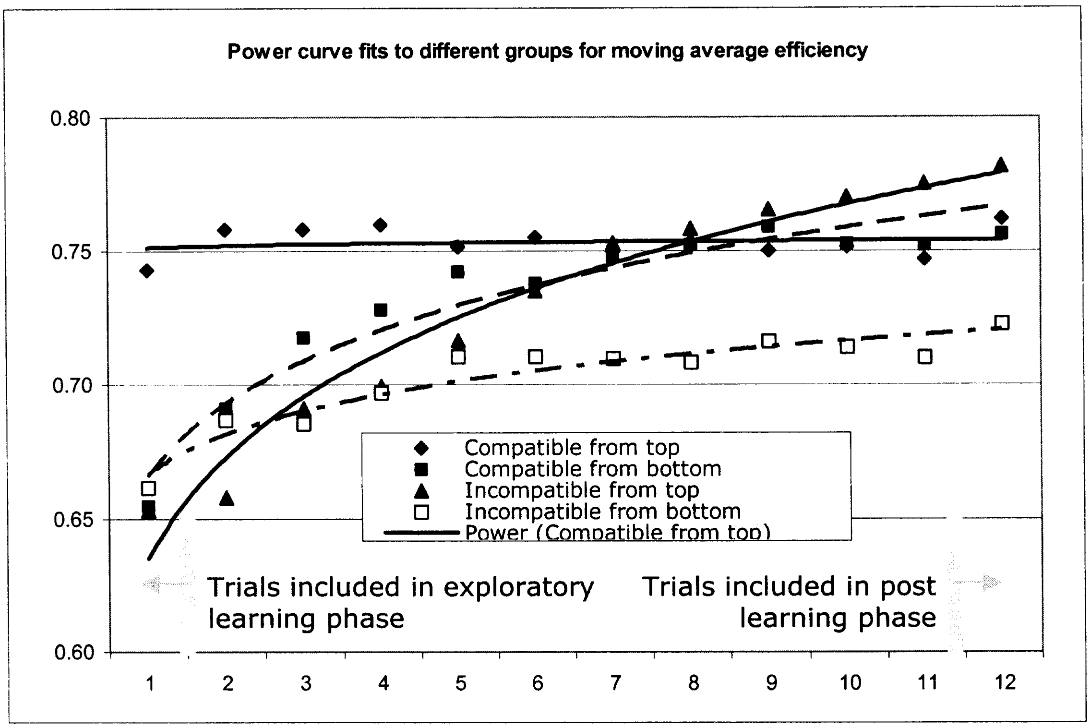


Figure 5.2 Power curve fits of efficiency across trials for different for different groups.

The average number of features in the first five tasks for all groups ranged from 40.3 to 41 while in the last five tasks they ranged from an average of 41.6 to 43.2 features with all combination of features (see Table 5.1 for details).

Table 5.1 Average Numbers Of features In The Exploratory and Post Learning Phases

	Exploratory Learning Phase (First five tasks)				**Post Learning Phase (Last five tasks)**			
Subjects	1	2	3	4	1	2	3	4
1	44	39	37	41	37	47	43	44
2	41	44	40	41	40	40	42	40
3	42	41	37	37	45	44	48	48
4	44	44	41	42	40	37	39	45
5	37	42	39	44	43	45	47	37
6	41	37	44	40	39	43	40	42
7	39	40	41	41	47	42	44	39
8	40	37	44	39	42	48	37	47
Average	**41**	**40.5**	**40.3**	**40.6**	**41.6**	**43.25**	**42.5**	**42.75**
St.dev.	**2.3**	**2.7**	**2.7**	**2.0**	**3.2**	**3.6**	**3.8**	**3.9**

Note: 1. Compatible from top
2. Compatible from bottom
3. Incompatible from top
4. Incompatible from bottom

5.1.2 Model For Repeated Measures Analysis Of Variance

The learning effect observed and described in section 5.1 suggests that the analysis should be conducted using a repeated measures analysis of variance model. This is compatible with previous studies using eye movements to develop measures of usability (e.g. McCarthy, 2001; Goldberg, *et. al,* 2002), suggesting the presence of learning effects. To study the effect of learning on eye movements, all the measures for studying the dependent variables of interest were analyzed using a repeated measures ANOVA for a between-within subject design where compatibility of task sequence requirement and tool arrangement were the between subject factors and the phase of learning was the within subject factor. To conform to statistical assumptions of normality, appropriate transformations were applied to the data providing the measures and the justification for using them are explained before the analysis results are presented.

Multivariate condition was not used since there were only two levels of within group factors and the type of variable for each analysis was the same. Also, the univariate tests for within-subject effects and interactions involving between group effects require some assumptions for the probabilities provided by the ordinary *F*-tests to be correct. Specifically, these tests require certain patterns of covariance matrices, known as Type H covariances (Huynh & Feldt, 1970). Data with these patterns in the covariance matrices are said to satisfy the Huynh-Feldt condition. A sphericity test is recommended along with the Huynh-Feldt condition to any set of variables defined by an orthogonal contrast transformation. However, when there are only two levels of the within-subject effect, there is only one transformed variable, and the sphericity test is not needed. Since only two blocks are used in this case (exploratory and post learning) the sphericity test was not required. The general linear model used for the analysis is given in Equation5.1 as:

CT (S X P) = U + C + T + CT + S + P +PC +PT +PCT + PS+ e.........Equation 5.1

Description of the symbols can be found in Table 5.2 given below.

Table 5.2 Summary Of Between And Within Group Factors For Final Experimental Design

Factors:	Compatibility (C)	Tool Arrangement (T)	Subjects (S)	Phases of learning (P)
Levels:	2	2	8	2
Description	Compatible/ Incompatible	From Top/ From Bottom		Exploratory/ Post learning
Type:	Between		Error	Within

Summary of the analysis and the between and within subject effects are also given in Table 5.2. The source of Mean Square Error and the respective effects with degrees of freedom and corresponding F-ratios used to interpret the effects are given in Table 5.3.

Table 5.3 Between-Within Design For Repeated Measures Analysis Of Variance For All Measures For The Experiment With Degrees Of Freedom (DOF), Mean Square Error (MSE) And *F*-ratios For Hypotheses Testing

Source	Description	DOF	F-test	MSE
[Mean]		1		
Between Subject				
C	Main effect of compatibility	1	F_C	MS_C/MS_E
T	Main effect of tool arrangement	1	F_T	MS_T/MS_E
C X T	Interaction of compatibility and tool arrangement	1	F_{CXT}	MS_{CXT}/MS_E
E: S / CT	Error term for between subject effects	28		
Within Subject				
P	Phase of learning (exploratory and post)	1	F_P	MS_P/MS_E
P X C	Interaction of phase and Compatibility	1	F_{PXC}	$MS_{P \times C}/MS_E$
P X T	Interaction of phase and tool arrangement	1	F_{PXT}	MS_{PXT}/MS_E
P X C X T	Interaction of phase compatibility and tool arrangement	1	F_{PXCXT}	$MS_{P X C x T}/MS_E$
E: P X S / CT	Error term for within subject effects	28		
Total		64		

A post-hoc comparison of least square means was carried out using a Bonferroni adjusted t-test for reducing the family wise error. In the following sections the overall experimental hypotheses of performance of subjects in relation to interface and supported task is demonstrated by carrying out hypotheses tests on performance measures and the measures based on mouse and eye movement data (see Section 4.8 for details of the measures used and how they correspond to the construct under investigation).

5.2 Experimental Hypotheses Of Interest For Efficiency Of Performance (E)

HA: *The relationship between graphical user interface display and embedded task sequence requirement can affect the* ***efficiency of performance*** *of the users and thereby the usability of the interface.*

The experimental hypotheses considered for testing the effect of compatibility of task sequence requirement and the tool arrangement on the interface display at different phases of learning were:

Between groups hypotheses:

The compatibility of the embedded task sequence with the display will affect the efficiency of performance.

For main effect of compatibility:

$$HA1_0: \ \mu_{\text{Compatible}} = \mu_{\text{Incompatible}}$$

$$HA1_1: \ \mu_{\text{Compatible}} \neq \mu_{\text{Incompatible}}$$

For main effect of tool arrangement:

The tool arrangement defining the display will affect the efficiency of performance of the subjects.

$$HA2_0: \ \mu_{\text{From top}} = \mu_{\text{From Bottom}}$$

$$HA2_1: \ \mu_{\text{From top}} \neq \mu_{\text{From Bottom}}$$

Within groups hypothesis:

The phase of learning will influence the efficiency of performance of the subjects.

$HA3_0$: $\mu_{\text{Exploratory}} = \mu_{\text{Post learning}}$

$HA3_1$: $\mu_{\text{Exploratory}} \neq \mu_{\text{Post learning}}$

Between within interaction hypothesis for efficiency:

User interfaces that are compatible with the embedded task sequence restrictions are more efficient in the exploratory learning phase. However, in the post learning phase the effect of compatibility will not influence the efficiency of performance.

$HA4_0$: $\mu_{\text{Exploratory}} = \mu_{\text{Post learning}}$

$HA4_1$: $\mu_{\text{Exploratory}} \neq \mu_{\text{Post learning}}$

5.2.1 Results Of Hypotheses Testing

Before computing the analysis of variance a test for normality was carried out. Since the sample group size was only 8 (number of subjects in each group = 8) a Shapiro Wilk test for normality was used. The results of the normality test are given in Table 5.4. The measure of efficiency for all the groups in both phases of learning showed a higher value for the Shapiro Wilk's statistic (*W*) thereby indicating that the normality assumption for the analysis of variance was valid.

Table 5.4 Shapiro Wilk's (W) Statistic For Test Of Normality Measure of efficiency for different groups at different phases of learning

Phase of Learning→	**Exploratory**		**Post Learning**	
Groups	**W**	**Pr < W**	**W**	**Pr < W**
Compatible from top	0.88	0.17	0.92	0.44
Compatible from bottom	0.99	1.00	0.82	0.05
Incompatible from top	0.88	0.19	0.91	0.37
Incompatible from bottom	0.89	0.25	0.89	0.23

The repeated measures analysis of variance (see Table 5.5) showed no main effect of compatibility or tool arrangement on the efficiency of performance of the subjects. Hence $HA1_0$ and $HA2_0$ were accepted at a significance of 0.05. An Interaction effect was not observed.

Table 5.5: Repeated Measures Analysis Of Variance For Efficiency For Univariate Tests Of Hypotheses For Efficiency

Between	**DF**	**SS**	**MS**	**F-Value**	**Pr > F**
C	1	0.005	0.005	0.52	0.47
T	1	0.01	0.01	1.54	0.22
C*T	1	0.01	0.01	1.19	0.28
Error: S (CXT)	28	0.27	0.01		
Within	**DF**	**SS**	**MS**	**F-Value**	**Pr > F**
P	1	0.10	0.10	**27.46**	**<.0001**
P*C	1	0.03	0.03	**8.14**	**0.01**
P*T	1	0.00	0.00	0.02	0.89
P*C*T	1	0.006	0.006	1.66	0.20
Error: P X S (CXT)	28	0.10	0.003		

In the within groups case, the phase of learning had a significant effect on the efficiency of performance ($F\ (1,\ 28) = 27.5$, $p<.001$) indicating an increase in efficiency of subjects in all groups. Hypotheses $HA3_0$ was rejected at a significance of 0.05.

There was a between-within interaction effect of phase of learning and compatibility ($F\ (1,\ 28) = 8.14$, $p<0.05$). This indicated that groups differing in compatibilities had different rates of learning and thereby reported different efficiencies in the exploratory and the post learning stages. Hypothesis $HA4_0$ was rejected at a significance of 0.05.

The rejection of the experimental hypotheses of $HA3_0$ and $HA4_0$ and the acceptance of the corresponding alternative hypotheses provided positive evidence for research hypotheses HA that compatibility had a significant effect on the efficiency of subject performance. However, this effect of compatibility of the task sequence requirement and the display structure did not affect the performance of the subjects throughout the trials. A post – hoc analysis was conducted to understand how the efficiency varied for the subjects across trials.

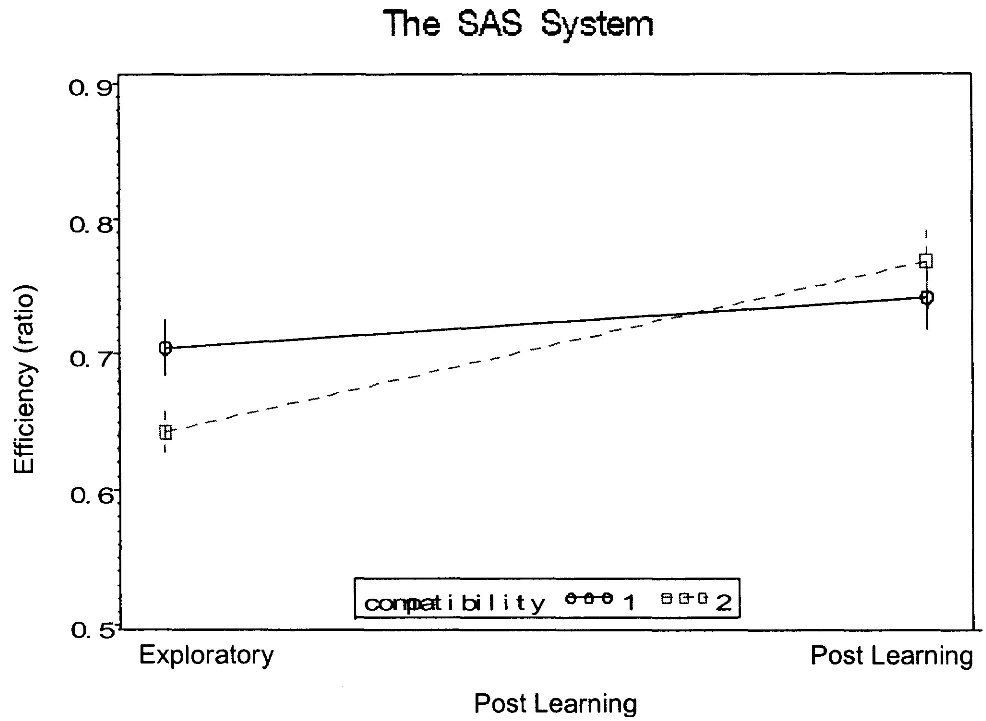


Figure 5.3 Means plot of efficiency across compatibility for different phases of learning.

The means plot of efficiency as a response plotted across groups differing in compatibility and different phases of learning is given in Figure 5.3.

The efficiency of the compatible from top group remained fairly steady (M = 0.74, SD = 0.09) from the exploratory learning phase to (M = 0.76, SD = 0.1) the post learning phase. For the compatible from bottom group there was an increase of efficiency from the exploratory phase (M = 0.66, SD = 0.05) to post learning phase (M = 0.72, SD =

0.08). For the incompatible from top group the efficiency increased from (*M* = 0.63, *SD* = 0.05) in the exploratory learning phase to the post learning phase (*M* = 0.78, *SD* = 0.09) and for the incompatible form bottom group there was also an increase of efficiency form the exploratory learning phase (*M* = 0.65, *SD* = 0.06) to the post learning phase (*M* = 0.75, *SD* = 0.09).

Compatible groups had a least square mean of 0.7 while incompatible groups had a least square mean of 0.64 in the exploratory learning phase. A t-test with Bonferroni adjustment suggested a difference ($t_{1,15} = 2.55$, $p < .05$) between the groups differing in compatibility only in the exploratory learning phase. In the post learning phase compatible groups had a least square mean efficiency of 0.74 while incompatible groups had a least square mean efficiency of 0.77. The groups did not show any differences in the post-hoc Bonferroni adjusted t-test ($t_{1,15} = -0.8$, $p > .05$).

5.2.2 Discussion

The results showed that the compatibility of task sequence requirement did not have a major influence on the compatible from top group. However, the study of individual learning curves indicated the existence of subject individual differences as regarding the response to the main effects. This can be observed by analyzing the performance curves of individual subjects. Figure 5.4 shows the plotted values of moving average efficiency for the subjects in the compatible from top group. It can be observed that subjects 5, 8, 4 and 3 almost had no learning. This tells that these subjects did not encounter the embedded task sequence when they performed the trials. However, the other subjects had significant increases in their learning and reached a plateau similar to their counterparts in the post learning stages.

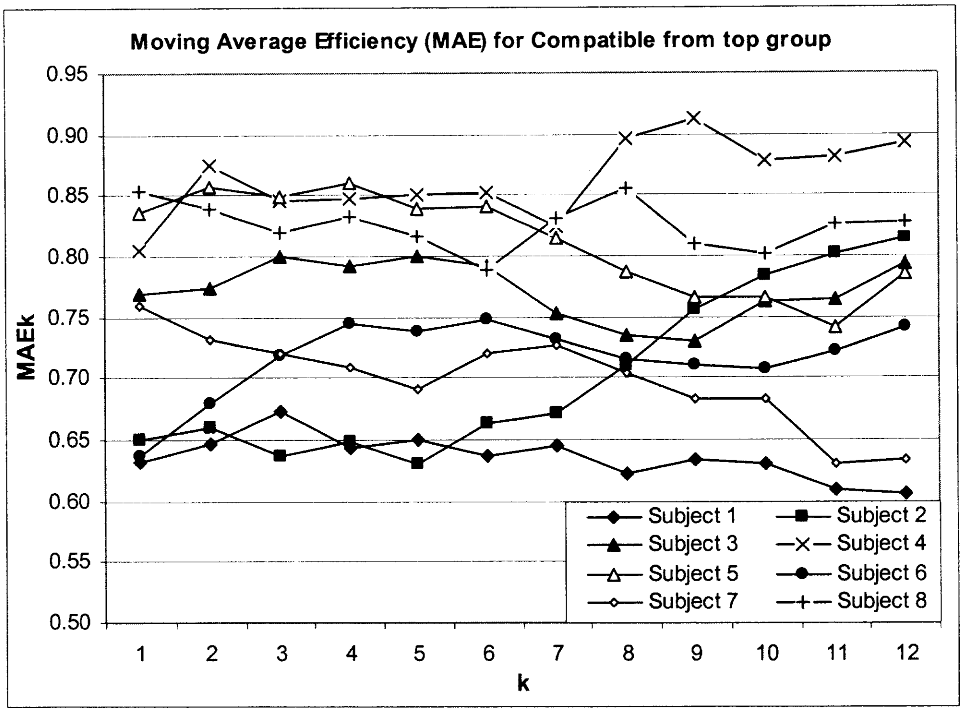


Figure 5.4 Moving average efficiency for compatible from top.

A closer look at Figure 5.5, 5.6 and 5.7 containing results from the compatible from bottom, incompatible from top, and incompatible from bottom groups respectively reveals that most of the subjects encountered difficulty with the embedded task sequence and had lesser efficiency in the exploratory learning phase. However, as the subjects gained knowledge and familiarity of the interface, their efficiency increased. It seems that subjects only in the compatible from top group responded to the display. Most of the subjects committed errors due to the embedded task sequence. Even in the case of incompatible from top groups some of the subjects had errors in the initial phase of learning.

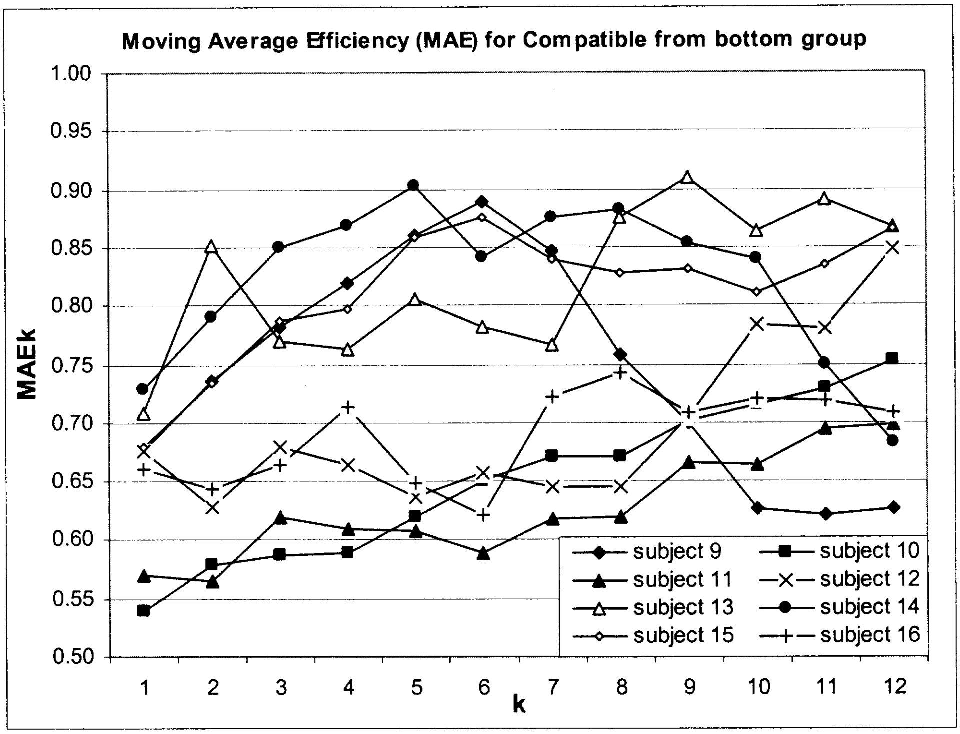


Figure 5.5 Moving average efficiency for compatible from bottom group.

In case of the incompatible from top group similar learning as in compatible from top group is observed. Most of the subjects initially come across the task sequence and later improve on their performance by improving their strategy and reducing their number of clicks. The learning rates for groups varied from 1% (a=-0.01) to 9% (a=-0.09%). Incompatible groups had higher learning rates than compatible groups. Subjects however showed individual differences in their learning and the interaction with the task sequence. This is explained in the following sections with individual learning curves. In this case also the moving average efficiency of the different subjects is taken into account. Values of individual learning rates are contained in Appendix D.

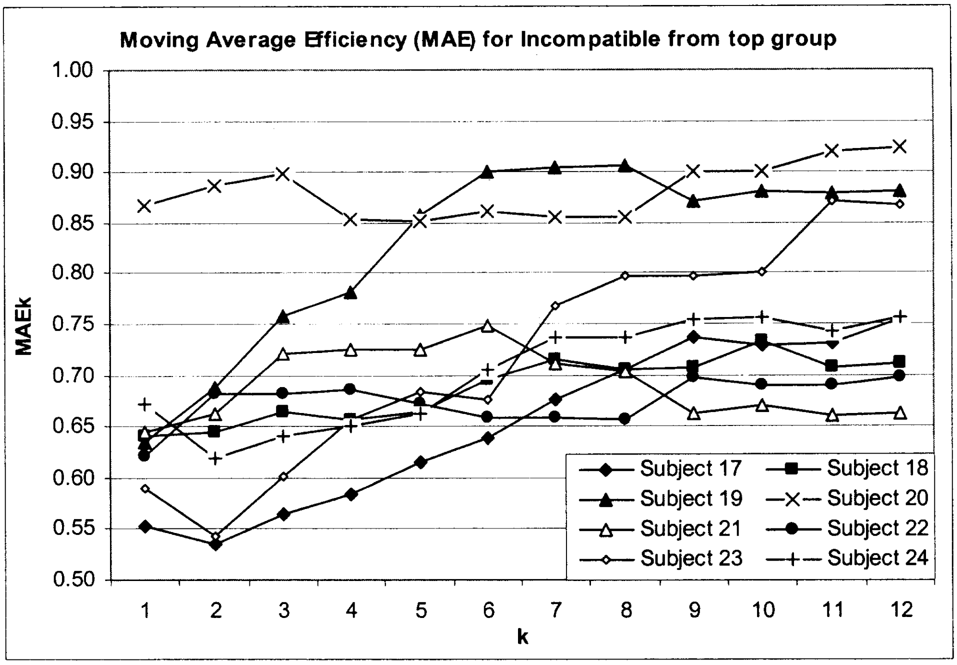


Figure 5.6 Moving average efficiency for incompatible from top group.

It can be concluded that although subjects may initially be guided by the display, their primary concern is to complete the task goal. The methods and operations required for achieving this goal may be different and the subjects may require different times to adjust to the task sequence restriction. Activity theory also suggests similar conclusions. However, it will interesting to explore whether the areas on the interface associated to the various notions of task performance suggested by Activity Theory do really reflect such phenomenon in terms of the mental actions and operations.

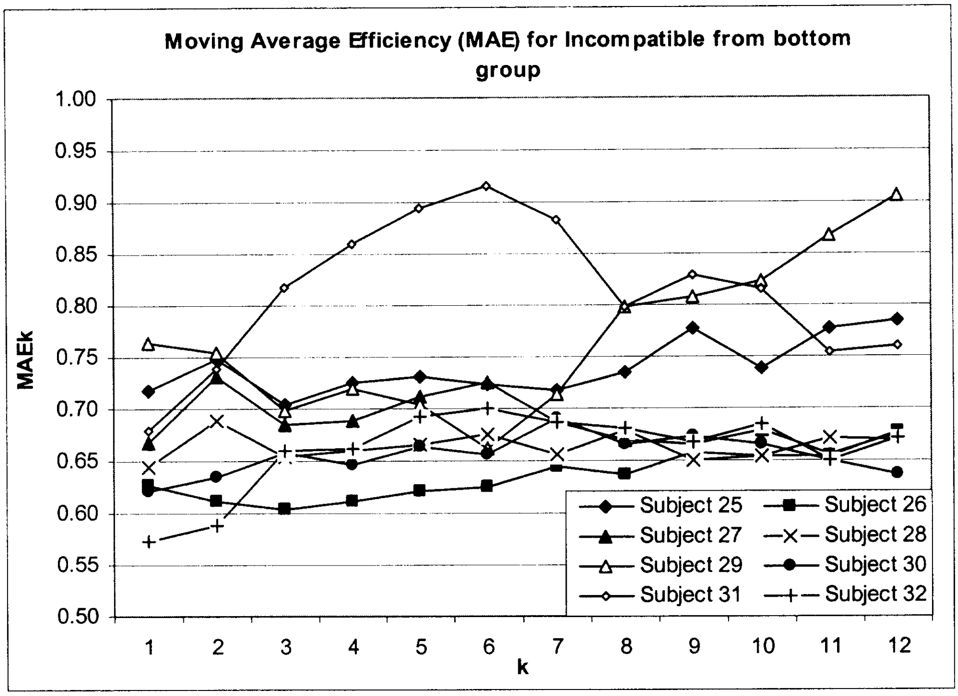


Figure 5.7 Moving average efficiency for incompatible from bottom group.

The power curves show that the learning rates in the incompatible groups were higher than those of the compatible groups. This is evident, as constraint based learning by users is more effective (Vincente, 1998) than instruction based learning. It has been suggested that operators learn more efficiently when they are allowed to face constraints and develop strategies of performance that are optimal. A similar effect is observed in this case. Subjects in the compatible form top groups did not have similar learning rates. However those subjects having problem with the task sequence had learning rates comparable to the subjects in the incompatible groups. This may be the reason why the groups did not show any differences when post hoc comparisons were performed.

5.3 Experimental Hypotheses Of Interest For Mouse Movements (MT)

Mouse movement based hypotheses

Mouse distance traversed per unit time (***MT***):

HB: *Interfaces differing in usability due to different task sequence requirements and interface display relationships can affect the* ***motor response (mouse movement)*** *of the users during task performance.*

The experimental hypotheses considered for testing the effect of compatibility of task sequence requirement and the tool arrangement on the interface display at different phases of learning were:

Between groups hypotheses:

For main effect of compatibility:

The compatibility of task interface relationship will affect the mouse distance traversed per unit time during task performance.

$HB1_0$: $\mu_{\text{compatible}} = \mu_{\text{in compatible}}$

$HB1_1$: $\mu_{\text{compatible}} \neq \mu_{\text{in compatible}}$

For main effect of Tool arrangement:

The display structure or tool arrangement will affect the mouse distance traversed per unit time.

$HB2_0$: $\mu_{\text{From top}} = \mu_{\text{From bottom}}$

$HB2_1$: $\mu_{\text{From top}} \neq \mu_{\text{From bottom}}$

Within groups hypothesis:

For main effect of phase of learning

The phase of learning will affect the mouse distance traversed per unit time.

$HB3_0$: $\mu_{\text{exploratory}} = \mu_{\text{post learning}}$

$HB3_1$: $\mu_{\text{exploratory}} \neq \mu_{\text{post learning}}$

5.3.1 Results Of Hypotheses Testing

Before computing the analysis of variance a test for normality was carried out. Since the sample size for the groups was only 8 (number of subjects in each group = 8) a Shapiro Wilk test for normality was used. The results of the normality test are given in Table 5.6. The measure of efficiency for all the groups in both phases of learning showed a higher value of the Shapiro Wilk's statistic (*W*) thereby indicating that the normality assumption for the analysis of variance was correct.

Table 5.6 Test Of Normality For Mouse Traversal Per Unit Time

Phase of Learning→	**Exploratory**		**Post Learning**	
Groups	**W**	**Pr < W**	**W**	**Pr < W**
Compatible from top	0.93	0.55	0.95	0.67
Compatible from bottom	0.91	0.33	0.99	0.99
Incompatible from top	0.93	0.51	0.96	0.77
Incompatible from bottom	0.88	0.20	0.84	0.07

A main effect of compatibility or tool arrangement on the Mouse distance traversed per unit time was not observed. Hence $HB1_0$ was accepted at a significance of 0.05. Interaction effect was not observed.

Within group tests showed a significant effect of phase of learning ($F\ (1,\ 28) = 9.08$, $p<.01$). Please see Table 5.7 for repeated measures analysis of variance for univariate tests of hypotheses. $HB2_0$ was rejected at a significance of 0.05.

Table 5.7 Repeated Measures Analysis Of Variance Tests Of Hypotheses For Between And Within Subjects Effects For Mouse Traversal Per Unit Time (MT)

Between	**DF**	**SS**	**MS**	**F-Value**	**Pr > F**
C	1	1353.4	1353.4	0.12	0.73
T	1	10961.4	10961.4	0.93	0.34
C*T	1	1244.2	1244.2	0.11	0.74
Error	28	329090.2	11753.2		
Within	**DF**	**SS**	**MS**	**F-Value**	**Pr > F**
P	1	21947.5	21947.5	9.08	0.005
P*C	1	23.7	23.7	0.01	0.92
P*T	1	28.7	28.7	0.01	0.91
P*C*T	1	5594.9	5594.9	2.32	0.13
Error(P)	28	67664.7	2416.5		

No between within interactions were observed. Evidence to support research hypotheses HB was not obtained. However, the significant effect of phase of learning on mouse traversal per unit time was clear evidence that subjects became more familiar with the sequence as well as the task and hence increased the access speed to the tools and the objects resulting in a slight increase in the mouse traversal rate.

The mouse traversal rate of the compatible from top group remained fairly steady (M = 308.7, SD = 80) from the exploratory learning phase to (M = 366.9, SD = 67.2) at the post learning phase. For the compatible from bottom group there was an increase of mouse traversal rate from the exploratory phase (M=363.7, SD=71.7) to the post learning phase (M = 381.9, SD = 60.9). For the incompatible from top group the mouse traversal rate increased from (M = 328.2, SD = 73.9) to (M = 346.7, SD = 65.8) at the post learning phase, and for the incompatible form bottom group there was also an increase of mouse traversal rate form the exploratory learning phase (M = 328.2, SD = 101.6) to the post learning phase (M = 381.4, SD = 129.3).

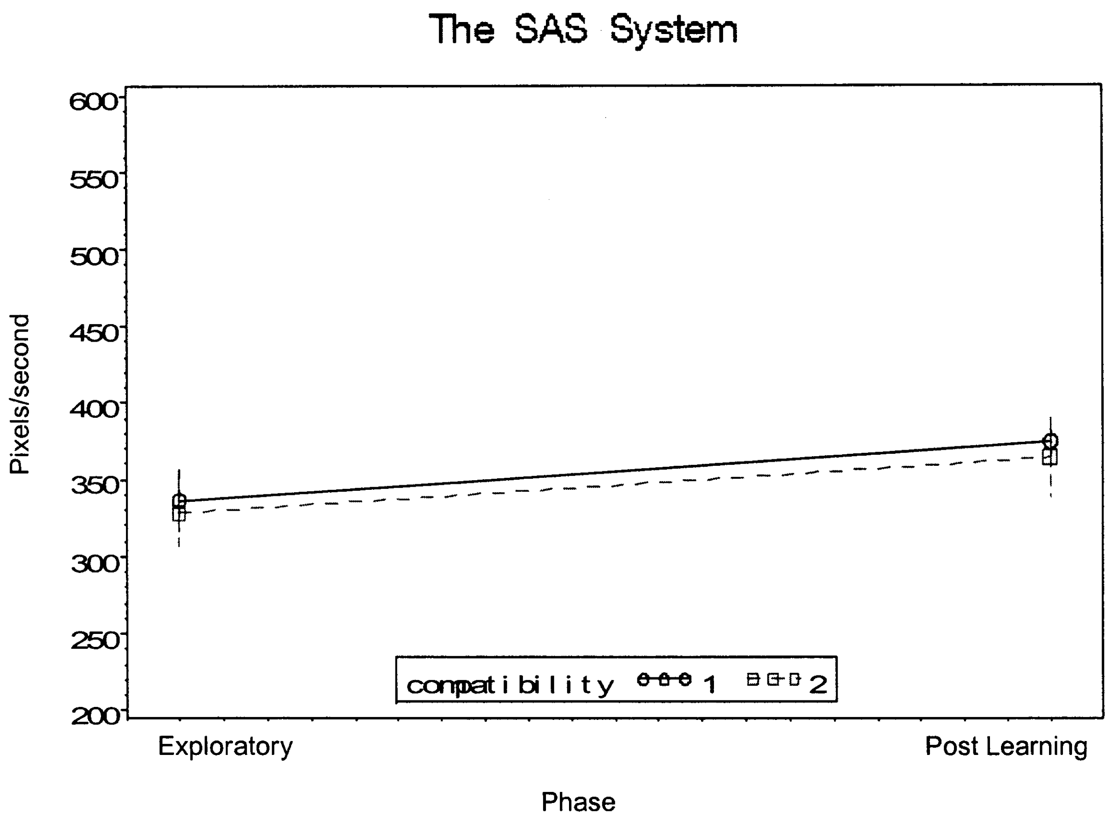


Figure 5.8 Means Plot of mouse traversal/second across compatibility for different phase of learning.

Compatible groups had a least square mean of 336.21 pixels per second while incompatible groups had a least square mean of 328.41 pixels per second in the exploratory learning phase. A t-test with Bonferroni adjustment suggested no difference ($t_{1,\,15}$=0.27, $p > .78$) between the groups differing in compatibility. Hence there was no significant main effect of the between group factors on mouse traversal

5.3.2 Discussion

If the task is considered to be of the same complexity and the number of features to be manipulated is fairly the same in the exploratory and the post-learning phase of the experiment, then the subjects required less time in the post-learning phase to traverse the same distance. Individual subject distances can be analyzed for understanding how these times to traverse similar distances varied across stages. This also corroborates the fact that Fitts' law cannot be directly applied to the prediction of task times in human computer interaction situations when complicated tasks are involved. Although, modeling of the movement times associated with the distances traversed was not carried out the increase in the mouse traversal rate exhibited by all the groups suggests that the similar distances were traversed in shorter times. It is to be noted that Fitts' law of movement time in general holds true. But in case of applying movement times to modeling of human computer tasks, the Fitts' law has been improvised to address different tasks. This may be a topic of further studies.

However, it can be concluded that users' mouse traversal rates and hence the motor response is affected by the interface display and learning. Previous studies by Mackenzie and Buxton (1992) and Accot & Zhai (1997) have shown that complicated human-computer tasks do not follow Fitt's law per se. The learning effect has to be taken into account, which reduces the cognitive overload of the subjects in due course as they become familiar with the interface. Although compatibility had no direct effect on mouse traversal rates, the effect of learning which was different for different groups was observed. The sequence hence affected this mouse distance traversed per unit time for all groups. This provides partial evidence in support of research hypotheses HB.

5.4 Experimental Hypotheses Of Interest For Eye Movement Measures

The research hypothesis for eye movement measures was:

HC: *Interfaces differing in usability due to different task sequence requirements and interface display relationships can affect the* ***search efficiency*** *(eye movements) by users during task performance.*

As discussed in the objectives, the eye movements were indicators of search efficiency. The existing literature has associated search efficiency with either the number of paths (saccades) generated by the eye or the amount of time the eye dwells (processing efficiency). Most of the measures are derived measures or rather a summarization of point of regard data on the basis of these two aspects of eye movements. The measures used for obtaining evidence in support of the research hypotheses are:

a) The total number of visits to the different areas of interest (indicating the search efficiency for accessing the tools and objects for task performance)

b) The average time per visit indicating the processing efficiency during search while performing a task.

It is noted that obtaining dwell times would have been a better measure but due to the unavailability of complete dwell time data the average time per visit was used.

In section 5.1.2 it was indicated that the total number of features completed by the subjects in different groups for the exploratory and the post learning stages ranged from a mean of 40 (*SD=2.7*) to 43 (*SD=3.6*) features. Considering the small range and similarity of features, the sum of all eye visits to the object and the tool area are considered for the exploratory and post learning trials.

5.4.1 Total Number Of Eye Visits (V)

Experimental hypotheses for the total number of visits to the different areas of interest.

Between Groups hypotheses:

For main effect of compatibility:

User interface compatibility of task sequence will affect the total eye visits to object and tool area due to confusion.

$HC1_0$: $\mu_{\text{Compatible}} = \mu_{\text{Incompatible}}$

$HC1_1$: $\mu_{\text{Compatible}} \neq \mu_{\text{Incompatible}}$

For main effect of tool arrangement:

User interface display due to tool arrangement difference will affect the total eye visits to object and tool area due to the difference in display layout.

$HC2_0$: $\mu_{\text{From top}} = \mu_{\text{From Bottom}}$

$HC2_1$: $\mu_{\text{From top}} \neq \mu_{\text{From Bottom}}$

Within groups hypothesis for:

Learning of the task sequence embedded in the interface will affect the total eye visits to object and tool area as the subjects learn the task sequence and improve their strategies for better performance.

$HC3_0$: $\mu_{\text{Exploratory}} = \mu_{\text{Post learning}}$

$HC3_1$: $\mu_{\text{exploratory}} \neq \mu_{\text{Post learning}}$

Across all tasks and across all subjects a total of 9892 visits were recorded from the video. Out of these 3465 were in the exploratory phase of learning and 2970 were in the post learning phase. About 3502 visits were recorded in the object area, 2153 in the tool area, and 2917 were recorded in the goal area. The total number of eye visits to all areas of interest was a count measure. Hence a *square root transformation* was applied to perform the repeated measures analysis of variance. The values of the means are reported in the retransformed form. However, instead of the standard deviation the coefficient of variation is reported. The formulation of the effect size statistic is not considered here for reporting actual estimates of the transformed standard deviations.

A repeated measures analysis of variance (see Table 5.8) showed no significant main effect of compatibility or tool arrangement. There is, however, a significant main effect of phase (F (1, 28) =12.63; *p<.005*). This indicated that subjects reduced the number of visits to the different areas of interest with course of time.

Table 5.8 Repeated Measures Analysis Of Variance Tests Of Hypotheses For Between And Within Subjects Effects For Total Number Of Visits To Different Areas Of Interest

Between	**DF**	**SS**	**MS**	**F-Value**	**Pr > F**
C	1	14.5	14.5	2.71	0.12
T	1	0.2	0.2	0.04	0.83
C*T	1	0.002	0.002	0.00	0.98
Error	12	64.5	5.37		
Within	**DF**	**SS**	**MS**	**F-Value**	**Pr > F**
P	1	9.4	9.40	12.63	0.004
P*C	1	0.10	0.10	0.14	0.71
P*T	1	0.77	0.77	1.04	0.32
P*C*T	1	0.18	0.18	0.25	0.62
Error(P)	12	8.93	0.74		

All the groups reduced the number of visits to the areas of interest from the exploratory to the post learning stages. For the compatible from top group, the mean total number of visits to the tool and the object area decreased from 221.3(*CV=3%*) to 199.9 (*CV=9%*), for the compatible from bottom group the mean number of visits decreased from 240.1 (*CV=14%*) to 191.3 *(CV=13%)*, for the incompatible from top group the mean number of visits decreased from 183.5 *(CV=6%)* to 162.2 *(CV=9%)* and for the incompatible from bottom group the mean number of visits reduced from 193.1 *(CV=17%)* to 163.0 *(CV=20%)*.

Post hoc comparisons although not required, did not show any differences between the groups due to the effect of compatibility of tool arrangement. There was also no interaction effect of learning.

Hypothesis testing with Lsmeans and a Bonferroni adjustment showed no differences between compatible groups ($t_{1,15}$=1.72, $p>.05$) in the exploratory learning as well as the post learning phase($t_{1,15}$=1.38, $p<0.2$). At a significance level of 0.05 $HC1_0$ and $HC2_0$ were accepted. However $HC3_0$ was rejected indicating substantial decrease in confusion of the subjects as they completed the trials. The significant main effect of phase on the number of eye visits indicated an improvement of search efficiency across the groups. However, no indications were observed of the fact that compatibility and tool arrangement had a significant effect on the number of visits.

5.4.2 Average Processing Time Per Visit (tv)

The average processing time per visit indicates the amount of time spent in each area of interest while performing the task. A higher time of processing indicates that the subjects spend more time in understanding the feature or deciding the next step of task execution. The variables that can affect this measure are the strategy used by the subjects and the individual differences in understanding the problem. The time duration data is *inverse transformed* for normality approximations.

Between groups hypotheses:

For main effect of compatibility:

The user interface compatibility of task sequence requirement with the display will affect the average processing time per visit due to difficulty in understanding the tool functions and their relationships during task performance.

HC4$_0$: $\mu_{\text{Compatible}} = \mu_{\text{Incompatible}}$

HC4$_1$: $\mu_{\text{Compatible}} \neq \mu_{\text{Incompatible}}$

For main effect of tool arrangement:

User interface display layout will affect the average processing time per visit due to difficulty in understanding the tool functions and their relationships during task performance.

HC5$_0$: $\mu_{\text{From top}} = \mu_{\text{From Bottom}}$

HC5$_1$: $\mu_{\text{From top}} \neq \mu_{\text{From Bottom}}$

Within groups hypothesis:

For main effect of phase of learning

Learning of the task sequence embedded in the interface will affect the average processing time per visit due to understanding of the task sequence requirement and familiarity with the display.

HC6$_0$: $\mu_{\text{Exploratory}} = \mu_{\text{Post learning}}$

HC6$_1$: $\mu_{\text{exploratory}} \neq \mu_{\text{Post learning}}$

Between-Within Interaction Hypotheses: *The* c*ompatibility of the task sequence requirement with the interface display will affect the importance average processing time per visit but this effect will depend on the phases of learning (HC7).*

A repeated measures analysis of variance (see Table 5.9) showed no interaction effect of compatibility and tool arrangement. A significant main effect of compatibility ($F(1, 28) = 11.9$, $p<.01$) was observed. There was no significant effect of tool arrangement. Within groups ANOVA showed no main effects and interaction effects.

Table 5.9 Repeated Measures Analysis Of Variance Tests Of Hypotheses For Between And Within Subjects Effects For Average Processing Time Per Visit To Different AOI

Between	DF	Type III SS	Mean Square	F Value	Pr > F
C	1	2.9	2.9	11.99	0.004
T	1	0.003	0.003	0.01	0.91
C*T	1	0.6	0.5	2.41	0.14
Error	12	2.9	0.2		
Within	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
P	1	0.05	0.05	0.76	0.39
P*C	1	0.00	0.00	0.00	0.96
P*T	1	0.00	0.00	0.01	0.90
P*C*T	1	0.05	0.05	0.71	0.41
Error	12	0.82	0.07		

For the compatible from top group, the mean of average processing time per visit was 0.65 seconds (*CV=31%*) in the exploratory learning phase and 0.58 seconds (*CV=40%*) in the post learning phase, for the compatible from bottom group the mean of average processing time per visit was 0.52 seconds (*CV=7%*) in the exploratory learning phase and 0.53 seconds *(CV=11%)* in the post learning phase, for the incompatible from top group the mean average processing time per visit was 0.78 seconds *(CV=34%)* and 0.79 seconds *(CV=39%)* and for the incompatible from bottom group was 1.05 seconds *(CV=11%)* and 0.91 *(CV=15%)* in the exploratory and the post learning phases respectively. The mean plots showing compatibility main effects and average processing time per visit in different phases of learning are given in Figure 5.9 and 5.10

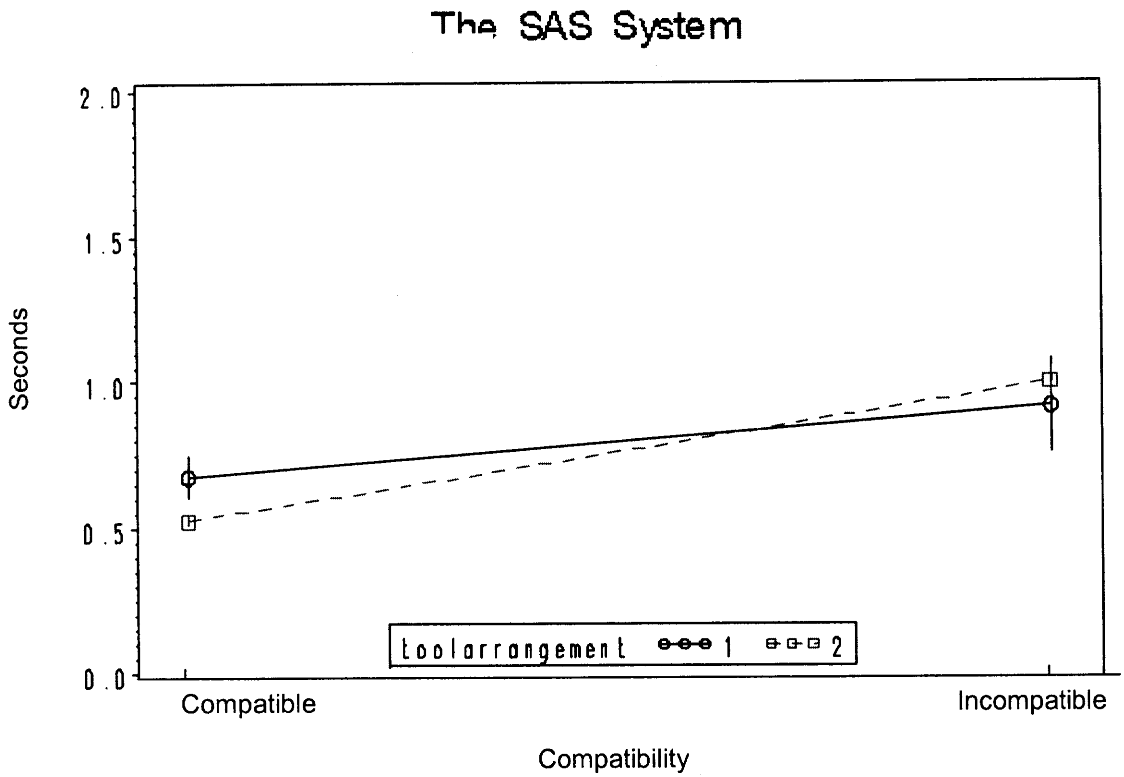


Figure 5.9 Means plot of average processing time per visit (for compatibility and tool arrangements effects).

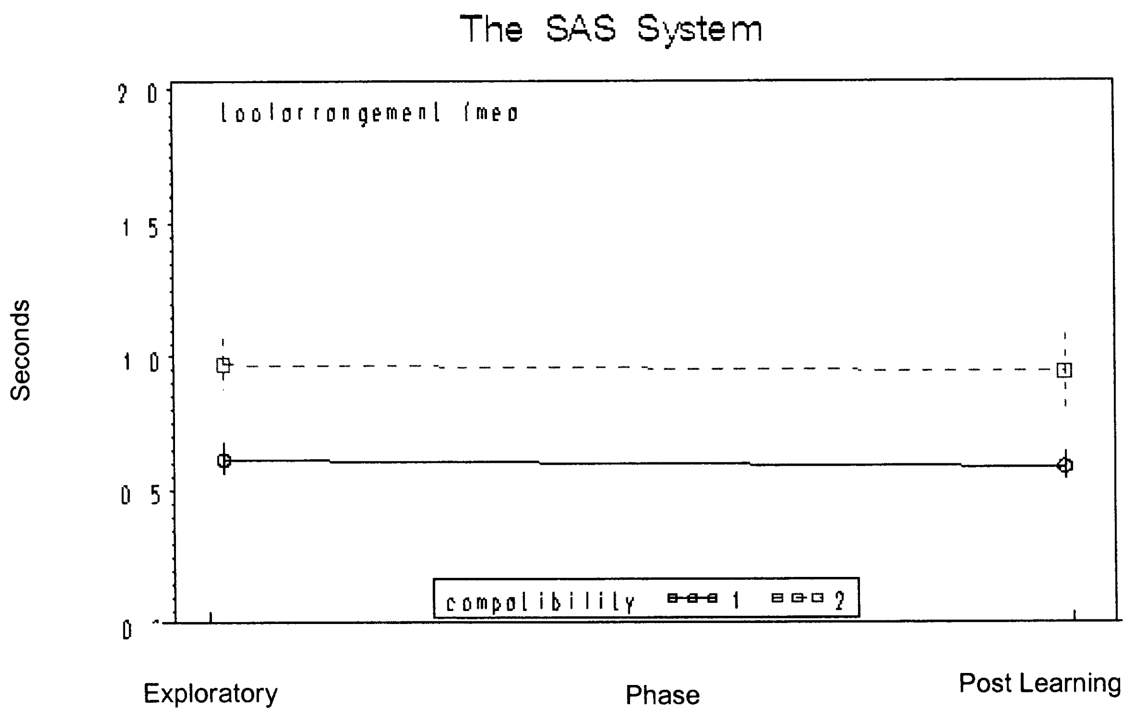


Figure 5.10 Means plot of average processing time per visit (for from bottom tool arrangement).

Bonferroni t-tests suggested a difference between groups with different compatibility levels. Compatible groups had a mean processing time of 0.58 seconds of average while incompatible groups had an average processing time of 0.90 seconds in the exploratory learning phase. In the post learning phase compatible groups had a mean processing time per visit of 0.55 seconds while the incompatible groups had a mean processing time of 0.84 seconds.

Hypothesis HC4 was further tested with lsmeans and a Bonferroni adjustment. HC4 was rejected at a t- value of ($t_{1,15}$=3.56, $p<.01$) in the exploratory learning phase. In the post-learning phase the lsmean of average processing time per visit for compatible groups was 0.55 seconds while for incompatible groups the average processing time was 0.84 seconds. Hence, hypotheses $HC4_0$ was rejected ($t_{1,15}$=2.71, $p<.05$). $HC5_0$, $HC6_0$ and $HC7_0$ were accepted.

5.4.3 Discussion

A significant effect of compatibility was observed in the case of average processing time per visit. It seems that the number of visits was reduced due to the search efficiency of tools to complete the task. But, the time it requires to activate the tool was affected due to the compatibility of the sequence with the tool arrangement. Although the visits got reduced, the subjects in the incompatible groups were spending more time in the tool area for deciding as well adjusting their mental task model. The results may have been influenced by the strategy of the subjects, but since only visits to the larger areas are considered, the strategy followed inside an area is not of consequence. This will be taken up in the next section on modeling of human performance. The compatible from bottom group, had less processing times but higher number of visits. Overall, sufficient evidence was obtained to conclude that although no differences between the groups were observed in the post learning phase for other measures, average processing time for the incompatible groups was significantly higher than that for the compatible groups.

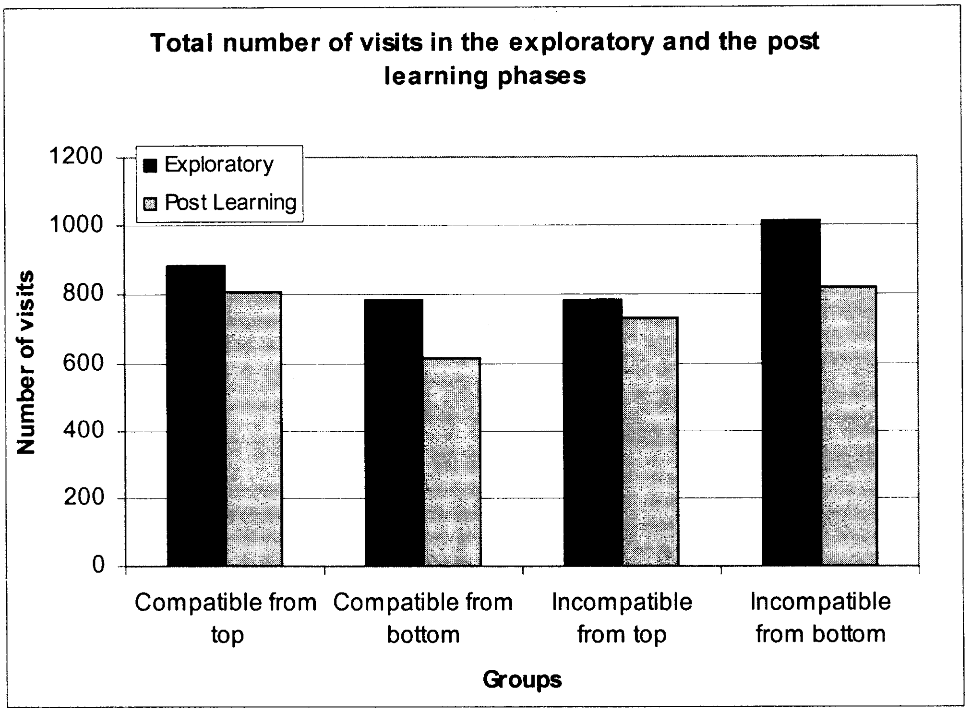


Figure 5.11 Total Eye visits to different areas of interest at different phases of learning.

The analysis of total number of visits showed a considerable decrease in the eye movement activity for the groups irrespective of the compatibility levels. Although, a main effect of compatibility and tool arrangements was not observed, the eye visits differed at different phases of learning. Figure 5.11 shows the total number of eye visits to the different areas of interest in the exploratory and the post learning phases for different groups. It can be observed that the number of eye visits for all groups was reduced due to learning. For example, the compatible from bottom groups reduced the number of visits from 783 to 615 visits. Compatible from top groups reduced the total visits from 886 to 805.

When consideration is given to the number of visits to tool, goal, and object areas then the picture becomes clearer as to how the subjects perform the task. Figure 5.16 shows the percentage distribution of the visits to the different areas of interest. In this case the percentage of visits to the object area is considerably higher (39% to 42%), while the tool area and the object area had a relatively smaller number of visits (23% to 30%) for the tool area and (27% to 34%) for the goal area. As a result, it can be suggested that most of the visits were focused towards the objects and the goal rather than the tools.

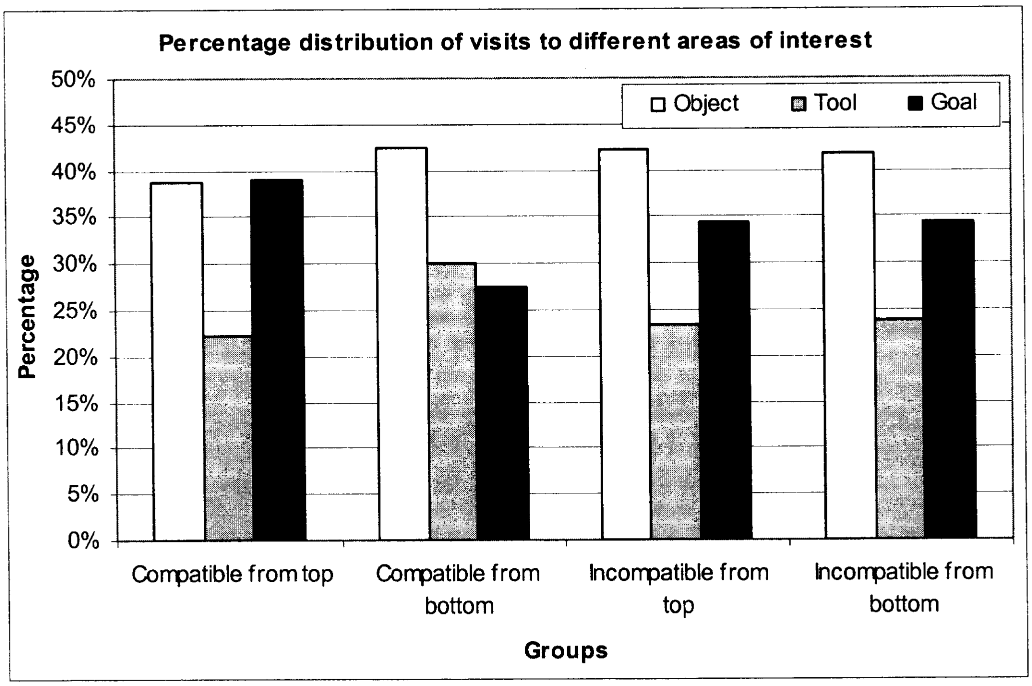


Figure 5.12 Distribution of eye visits to different areas of interest.

Using Fitts' Law conclusions, ratio of eye visits to object area over of eye visits to the tool area (ETO) was used to understand how the subjects attributed importance to these key areas of interest. A higher importance of the tool area indicated by a lower ETO suggests that the subjects experience difficulty with the tools. The increase in ETO suggests a shift of focus of the subjects from the tools to the objects. For regular interfaces, usability researchers can just identify these areas and then focus their analysis on their relative importance to estimate usability during task performance. The support of the interface for learning a particular task can also be investigated by observing the change in the focus of the subjects to the areas of interest.

The efficiency of the subjects indicated that although there is an effect of interface usability on user performance, the subjects adjust their strategy by learning the embedded task sequence and hence the influence of task interface relationship giving rise to compatibility or incompatibility will not influence the performance. Also, mouse movement per unit time showed that users increase their speed tool access as indicated by the increase in mouse distance traversed with a subsequent increase in efficiency. An additional investigation into the dwell time of subjects in the areas of interest is presented here. This might provide additional clues as to whether there was any difference between the interfaces in the later stages of learning or the interfaces were actually the same to the subjects irrespective of the usability levels governed by the task and interface relationships. Figure 5.12 shows the percentage dwell times for four different subjects during a task in the exploratory learning phase from four groups, which were the focus of this study. It can be seen that percentage dwell times in the tool, object, and goal area were more or less similar irrespective of the groups. Although the subjects performed more eye visits during this stage for the lower usability groups, the dwell times were more or less the same.

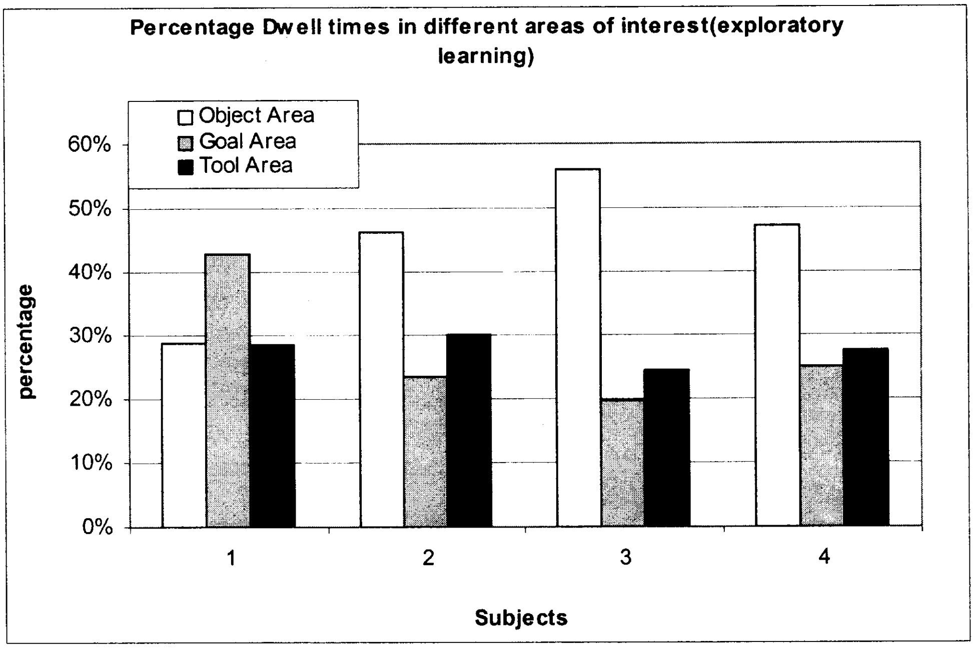


Figure 5.13 Percentage Dwell times in the different areas of interest in the exploratory learning stage.

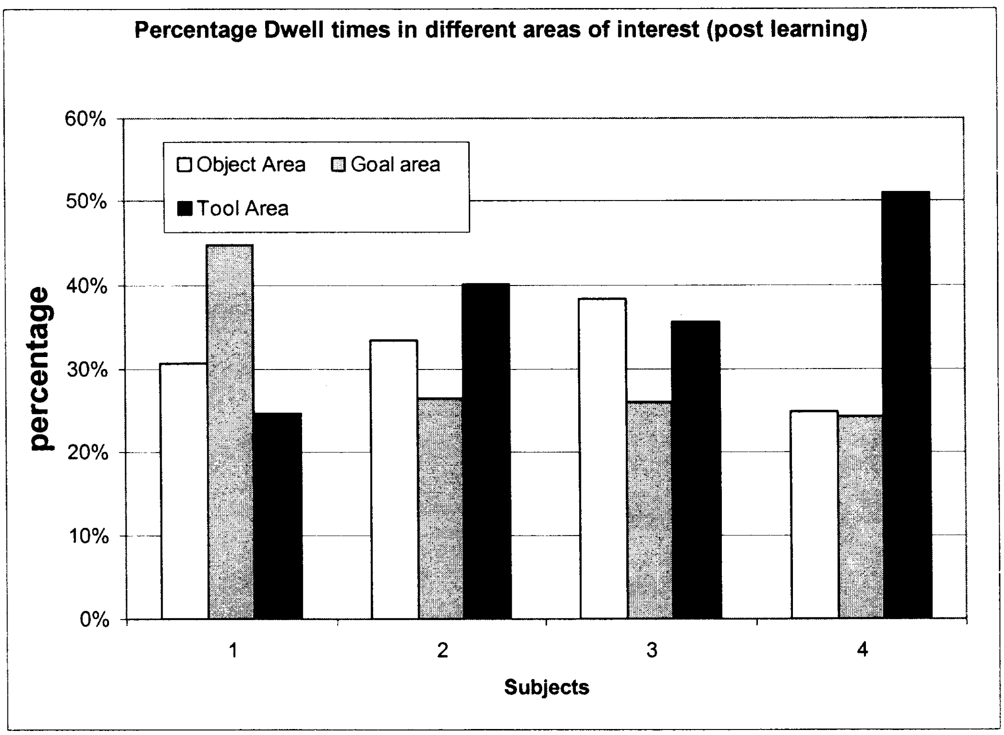


Figure 5.14 Percentage Dwell times in the different areas of interest in the post learning stage.

Figure 5.14 shows percentage dwell times for the subjects in the post-learning phase. In this phase the users in the incompatible groups can be observed to spend more time in the tool area than in the object or the goal area. This suggests that although the users were accustomed with the tools and the functional requirements of the task sequence, a difficulty was observed due to the unnatural task sequence they had to follow.

Figures 5.15 to 5.17 give the change in percentage dwell times from exploratory to post learning stages in the different areas of interest. In case of object area, the subject from compatible from top group has less percentage dwell times than the other subjects. Compatible from bottom and incompatible groups show a relatively higher percentage dwell times in the object area. All the groups reduce the percentage dwell times in the object areas across trials. This is indicated by the lesser percentage dwell times in the post learning stages. (see Table 5.10 for details).

Table 5.10 Percentage Dwell Times In Different Areas Of Interest For Representative Subjects

	Object		**Goal**		**Tool**	
Subject	**Expl.**	**Post**	**Expl.**	**Post**	**Expl.**	**Post**
1	28.8	30.6	42.8	44.7	28.3	24.6
2	46.3	33.4	23.5	26.4	30.0	40.1
3	56.0	38.3	19.5	26.0	24.4	35.6
4	47.3	24.8	25.1	24.3	27.5	50.9

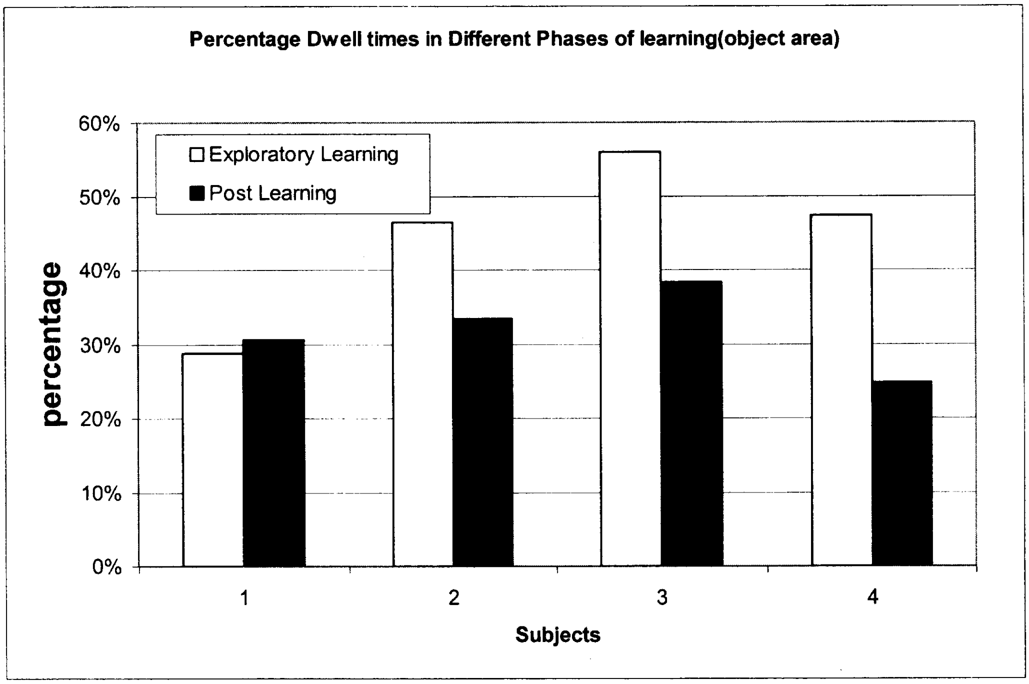


Figure 5.15 Percentage dwell times in the object area for exploratory and the post learning phase.

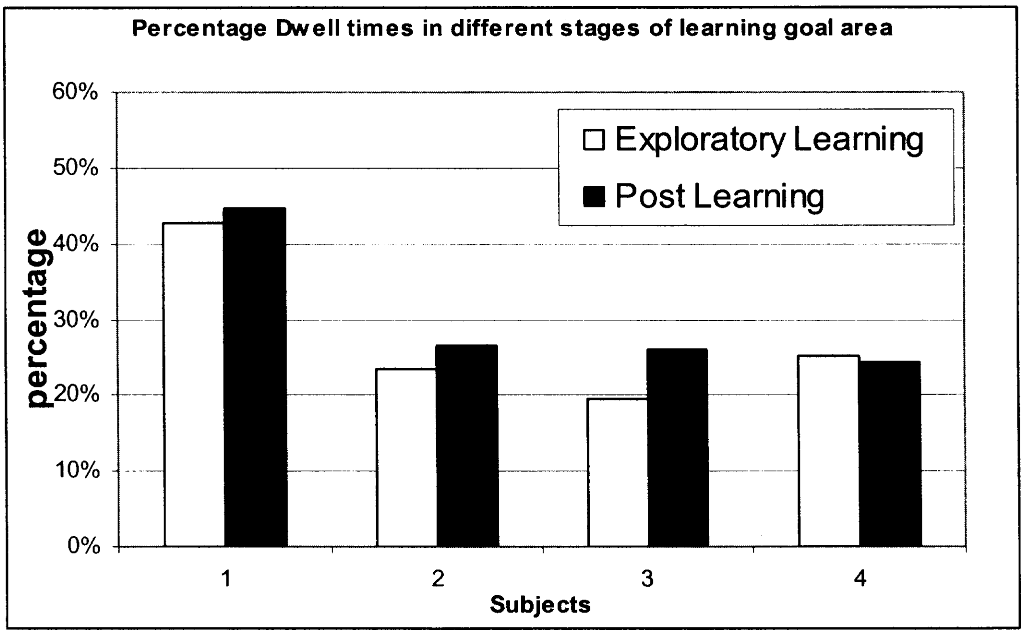


Figure 5.16 Percentage Dwell times in the goal area for exploratory and the post learning stages.

In the case of percentage dwell times in the goal area (see Figure 5.16), the subject from the compatible from top group had higher dwell times than those of other subjects. The percentage dwell time for the subject in the compatible group was 42% and increased to 44% only. On the other hand, subjects in the other groups had far lower percentage dwell times in the goal area. This suggest that subjects in the incompatible and the compatible from bottom groups were more engaged in manipulating the objects and understanding the tools than focusing on the task at hand.

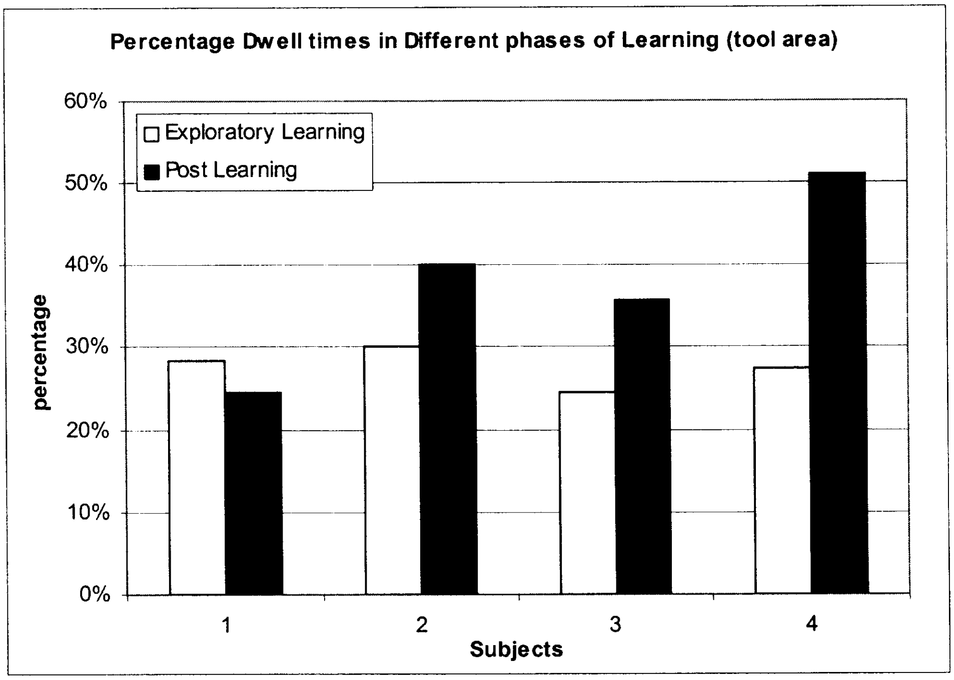


Figure 5.17 Percentage Dwell times in the tool area for exploratory and the post learning stages.

In the case of percentage dwell times in the tool area (see Figure 5.17) the percentage dwell times were higher for the subjects in the compatible from bottom and incompatible groups.

5.5 An Approach To Modeling Human Performance

Previous research (Byrne, et. al., 1997, Smith et. al., 2000; Hornof, 2000) suggested that the eyes guide the cursor to the different areas contains elements of interests and the target. Due to this close relationship, Hornof (2000) used a separation technique to understand the satisfaction of search exclusively from the cursor movements. All the findings point to the direction that eye and mouse movements, being indicators of cognitive processes and performance, can be used to study and model a human computer interaction task. Systemic-structural theory of activity (Bedny, 1997) advocates the use of unity of cognition and behavior principle for the ***study of human computer tasks.***

The final objective of the study was to use eye and mouse data as a tool to model human performance. The basis of this approach was discussed in the literature review and a detailed discussion can be found in Appendix F. Here a general understanding of the methodology is described. This method is under continuous improvement and researchers (Harris, 2004; Karwowski, Bedny & Jeng, 2004; Karwowski & Bedny, 2005, in press) have adopted for application to fields like cognitive walkthrough and situation awareness. It should be noted that without the experimental study it would have been impossible to understand the correspondence between eye and mouse movements. Since the measures based on these processes reflected user performance on the graphical user interface, it was deemed suitable that eye and mouse movements can be used for the study of human computer interaction using the systemic-structural approach to activity (Systemic-Structural Theory of Activity).

5.5.1 Eye Movement And Gaze As Unitary Action

Researchers have suggested different types of eye movements depending upon the combinations of saccades and fixations presented in Table 5.11. The possible combination of saccades and fixations as a function of their duration is presented.

Table 5.11 Possible Combinations Of Saccade And Fixations And Resultant Eye Movement Characterization

	FIXATIONS		
SACCADES	Duration	Small	Large
	Small	**Gaze**	**Gaze**
	Large	**Eye Movement**	------

It is important consider the fact that the characterization of eye and mouse movements as saccades and fixations depends on the sampling rate and the accuracy of the algorithms identified. In this however a series of fixations followed by minute saccades is considered as a gaze is considered as action. The value of the time is based on the video analysis and is hence not influenced by the inconsistencies of regularly used algorithms (Salvucci & Goldberg, 2000). Further more the increased area of interest assures that the approximation of time periods being associated to the movements and gazes is fairly consistent and reflective of the times involved by users for processing of information at the particular area. This different eye movement characterizations of the table are useful for cognitive psychology and activity theory. An association of a small saccade with a small fixation results in a small gaze duration. A series of small fixations and large duration fixations provides what is known as a gaze and finally a series of high amplitude saccades with small fixations constitute what is known as eye movement.

Based on this study formalized rules can be introduced so that the eye movement data can be separated into movement and gaze pairs. These rules include:

1. Since saccades are very quick, it is not possible to execute complex mental operations during such short durations.
2. Mental operations performed during a gaze constitute different operations associated with receiving information, interpretation etc.
3. The final stage of a gaze includes a program of performance for the corresponding saccades. This is the point of separation of two corresponding actions. As a result, one complete eye movement and one complete gaze duration following this eye movement is characterized as one complete action.

The summation of the movement time and the associated gaze time provides the total approximate time of action. For example, the movement time to the tool area is 100 milliseconds and the gaze time in the tool area is 300 milliseconds, to complete the action of activating the tool, the user has to locate the tool, then select it mentally and execute the action while gazing at the particular area. Hence, the total time of action is given by movement time plus the gaze time, which in this case is 400 (100+300) milliseconds.

5.5.2 The Action Classification Table

The action classification table (denoted as tabular presentation of activity elements in Table 5.12) is based on the qualitative analysis of eye movement data from the video and the duration of gazes in different areas. Since dwell times are associated with a particular area in the screen, it gives the opportunity to associate these times with the duration and content of the mental action. The sequence of gazes and movements provides a logical organization of mental actions.

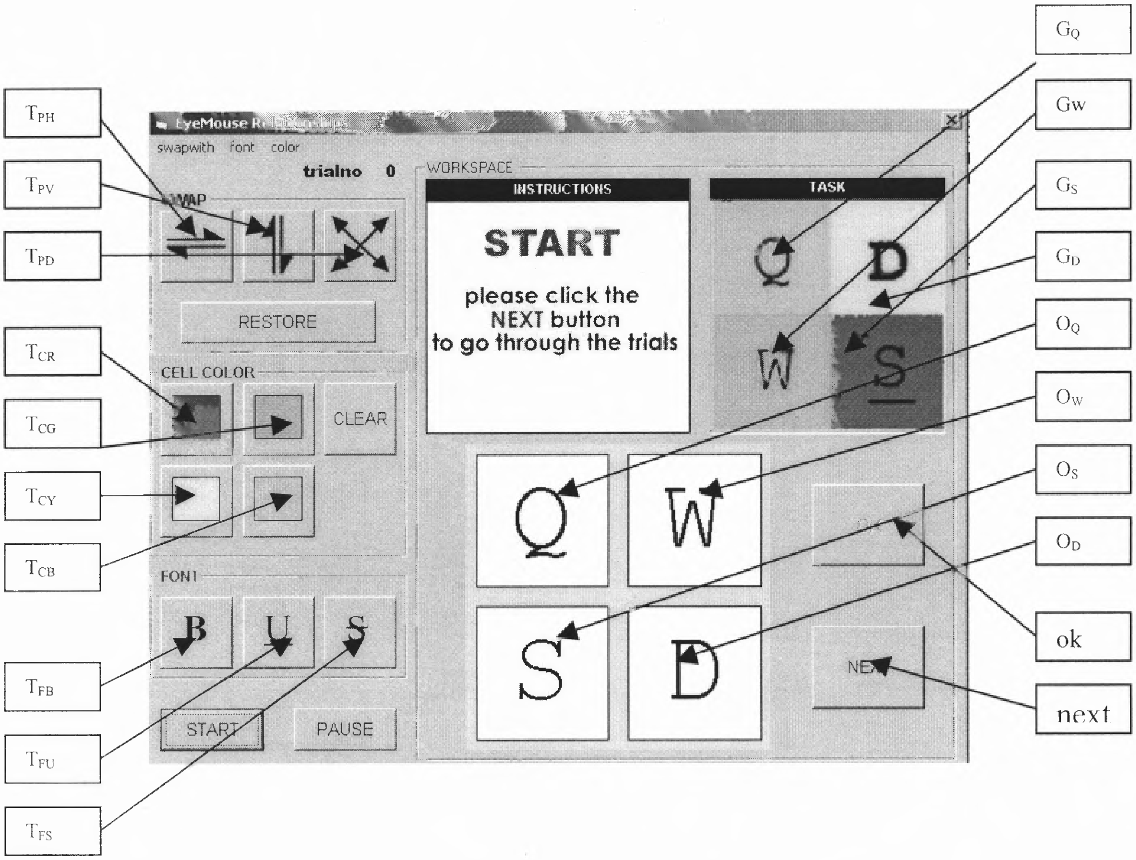


Figure 5.18 Coded interface objects for mouse event logging and eye point of regard (POR) qualification.

Motor actions, which are performed simultaneously, are obtained from the mouse event data and are also used to classify these organized actions. Column 1 contains the start and end position of the eye during one complete movement and dwell which changes the focus of the eye. The association of eyes with the position of the interface elements is based on an approximation of the position of the eye to the nearest element on the screen. For designation of the start and the end position symbols representing the interface elements explained earlier have been used. For example, the first transition represents the movement of the eye from the "start" position to the element G_Q (goal area - final state of Q) . All the other elements and their designations are given in Figure 5.18. These designations are used in the action classification table to indicate the shift of the eye position from one particular element to another. The total time it takes the eye to move start position to position G_Q is 150 milliseconds (given in column 4a.). The dwell times at the end position (i.e. at G_Q) or the fixation time in case there is no dwell (durations less than 200 ms) is given in column 4b. The summation of all the elements of times, represented in column 4a and 4b is given in column 5

Consider an example for a particular case in systemic-structural analysis of the experimental task. Figure 1 at Table 5.12 shows the first set of a scan path till the first mouse event. The eye scan path suggests comparisons taking place between the final required state and the initially given state. After careful comparison of the elements, the subject selects element O_D.

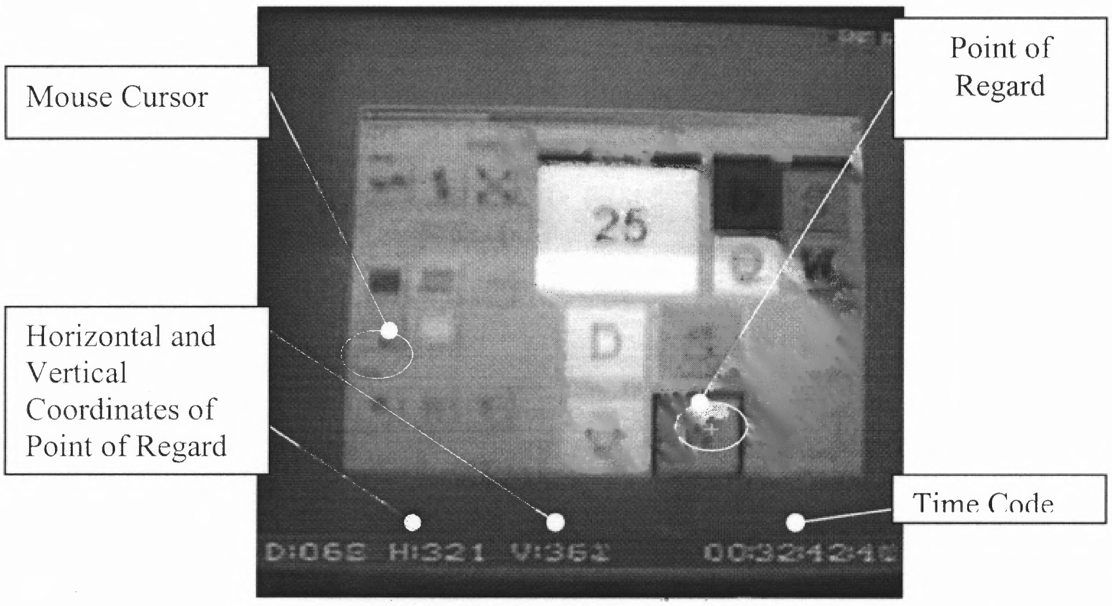


Figure 5.19 Video Showing Point of Regard and Mouse Cursor.

Knowing only the scan path will not give the total picture. On the basis of the scan path it is known that the eye has visited particular places. But how much importance or attention each place required can be obtained based on the dwell times during the scan path. This can be obtained from columns 4a and 4b adjacent to Figure 1. 4a represents the total time for movement and 4b represents the time for dwell. It is interesting to take into account the fact that the subject in this case spends the most of the time on O_D , Ow, O_D and G_D and finally selects O_D . The sequence of eye movement along dwell time (obtained on the basis of time code on the video shown in Figure 5.19) suggests that the subject is more inclined to act on object O_D and might consider switching the position of the objects O_D and O_W.

In the Figure 1, eye movements are more or less concentrated in the goal and object areas. This is due to the process of comparison and thinking actions required to evaluate the task and initiate a plan of action. It can be noticed that only once the eye visited the tools area. This primary focus on the object and the goal areas for developing the program of performance is well according to the theory of evaluation phase of Norman (1983). Considerable dwell times can be seen on objects and the goal area. In Figure 2, the focus shifts to the tool area to choose from the array of tools available for the corresponding task. The scan path in Figure 2 suggested a sequence Start-G_Q-O_q-T_{CB}-G_S-G_D-O_q-O_W-O_D.

5.5.3 Algorithm Of Performance

Human-computer task consists of various mental and motor processes with mental actions being more complicated and motor actions being less complicated. A micro-level algorithm provides an effective description of the situation when activity consists of small duration cognitive actions. Hence, this study is based on a micro-level algorithmic description of activity during task performance. A detailed explanation of the procedure can be obtained from the Encyclopedia of Human Factors and Ergonomics, 2005 edition. The algorithm depicts the model of human performance.

The complete model is devised on the basis that eye movements correspond to the cognitive processes and the mouse movements and the actions correspond to the actions of the users based on these processes. Hence, the time structure obtained is based on the time measures obtained form the eye and the mouse movements. The results of the experimental study conclusively prove that the usability of the computer interface affects eye and mouse movements and hence can be used to study and compare human performance through modeling based on the basis of systemic-structural approach. The uniqueness of the approach lies in the fact that it takes into account all the processes and derives the model. Whereas normal task analysis procedures would find it difficult to associate mental actions and operations to the time structure, systemic-structural theory can interpret the actions both logically by observing the mouse movements and the eye movements and with durations obtained form the eye movement. They are then associated to different algorithms of performance. The algorithm of performance developed, can be studied individually to improve the interface or the task.

Table 5.12 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration

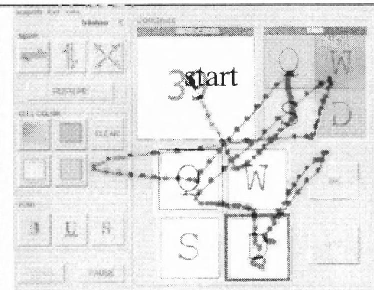
1		2	3	4		5		6
Eye Move And Final Position		**Activity between successive mouse events(clicks)** Mental/ motor Actions Involved	Mouse events	Time (ms)		Total Action Time (a+b)		Scan path generated/duration
From	To			a. Approx Eye Movement time to reqd. position (ms)	b. Approximate Dwell time at position (ms)			
Start	G_Q	Goal acceptance and formation and creation of subjective model of situation; selection of object (O_D) for subsequent subtask execution. (Includes simultaneous perceptual actions, with explorative thinking. Comparison of object and goal in relation to the program of performance)		150	180	330	Simultaneous perceptual actions	 Figure 1
G_Q	O_q			150	220	370	Simultaneous perceptual actions	
O_q	T_{CB}			180	150	330	Simultaneous perceptual actions	
T_{CB}	G_S			180	220	400	Thinking action based on visual information	
G_S	G_D			150	190	340	Thinking action based on visual information	
G_D	O_q			210	220	430	Thinking action based on visual information	
O_q	O_W			150	330	480	Thinking action based on visual information	
O_W	O_D			150	190	340	Thinking action based on visual information	
O_D	G_D	Decision on program of performance and motor action based on decision.		210	190	400	Thinking action based on visual information	
G_D	O_D	Perceptual action with motor action and thinking based on program of performance	Click object element D with mouse	210	630	840	Decision making action at sensory perceptual level. With simultaneous Motor action	

Table 5.12 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

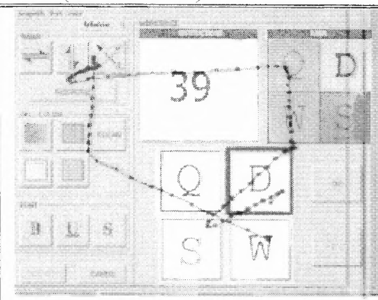
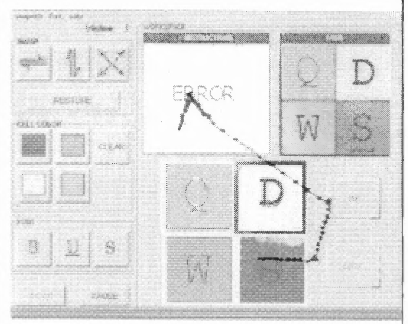
O_D	T_{PV}	Motor action of eye and mouse along with selection from choice of tools		210	220	430	Simultaneous perceptual action with motor action	 Figure 2
T_{PV}	G_D	Eye move to goal area with mouse stationary at tool. Use of peripheral vision for mouse control while focus on goal area.	Click vertical positioning tool.	150	420	570	Simultaneous perceptual action Decision making action during visual assessment. Motor action;	
OK	G_S	Corresponding perceptual action on feedback and goal for assessing incorrectness and incompleteness in task.		150	220	370	simultaneous perceptual actions	 Figure 10
G_S	Feed			150	210	360	simultaneous perceptual actions	
Feedback	G_W			120	540	660	thinking action with simultaneous perceptual actions	

Table 5.12 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

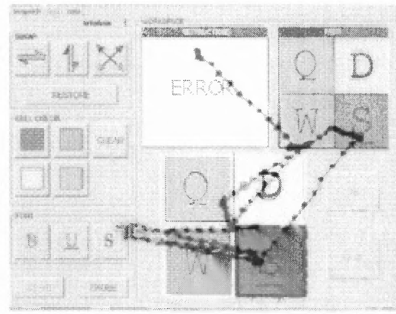
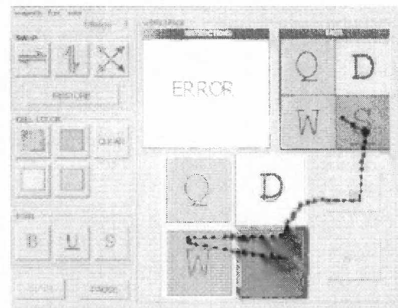
G_W	O_Q	Revisit objects for detection of error perceptual actions with memory action		150	600	750	Memory action , thinking action with simultaneous perceptual actions	 Figure 11
O_Q	G_S	Visit goal for finalizing program of performance based on error detection Decision on program of performance		180	220	400	Simultaneous perceptual action	
G_S	O_S	Motor action for executing program of performance	Select object s	150	220	370	Decision making with motor action	
O_S	T_{FU}	Tool selection for correction of error.	Remove strike	150	220	370	Simultaneous perceptual action with motor action	
T_{FU}	O_D	Final comparison of goal and acceptance of completion of task	Click underlin e	150	280	430	Simultaneous perceptual action with motor action	
O_D	OK		Finish	120	390	510	Memory action Thinking action and Decision making at sensory perceptual level	 Figure 12
OK	Finish						Simultaneous perceptual action with motor action	

Table 5.13 Algorithm Of Performance

Algorithm	Description	Actions obtained from action classification table	Time (ms)
O_1^{α}	Look at goal area and initial state of object area.	Simultaneous perceptual actions (3 actions)	1030
$O_2^{\alpha th}$	Find out differences between goal area and object area.	Thinking actions based on visual information (4 actions)	1650
$O_3^{\alpha th}$	Find out differences between goal area and object area and simultaneously perform O_4^{ε}	Thinking actions based on visual information (2 actions)	740
O_4^{ε}	Move cursor closely to object area.	Simple motor action.	
l_1	Decide to click object (element O_D) and simultaneously perform O_5^{ε}	Decision making action based on information from memory.	840
O_5^{ε}	Simultaneously with l_1 , click object element O_D	Simple motor action.	
O_6^{α}	Look at tool area and simultaneously perform O_7^{ε}	Simultaneous perceptual action	430
O_7^{ε}	Simultaneously with O_6^{α} move cursor closer to tool area.	Simple motor action	
l_2	Decide to click object (element O_D) and simultaneously perform O_8^{ε}	Simultaneous perceptual action Decision making action during visual assessment.	570
O_8^{ε}	Simultaneously with l_2 move cursor close to specific icon and click icon	Precise motor action	
$O_9^{\alpha th}$	Evaluate how object area matched to goal area.	Thinking action based on visual information	400
$O_{10}^{\alpha th}$	Evaluate intermittent state of object area.	Thinking actions based on visual information (4 actions)	1740
O_{11}^{α}	Look at goal area and then look at tool area	Simultaneous perceptual actions (2 actions)	
l_3	Decide to click object (element O_s) and simultaneously perform O_{12}^{ε}	Decision making action at sensory perceptual level.	280
O_{12}^{ε}	Simultaneously with l_3 , click object element O_s by using mouse.	Simple motor action.	
O_{55}^{α}	Look at tool area and simultaneously perform O_{57}^{ε}	Simultaneous perceptual action with motor action	400
O_{56}^{ε}	Move to tool element bold	Precise motor action.	

Table 5.13 Algorithm Of Performance (continued).

O^{α}_{57}	Look at goal area and simultaneously perform O^{ε}_{59}	Simultaneous perceptual action with motor action	360
O^{ε}_{58}	Click bold tool	Simple motor action.	
$O^{\alpha th}_{59}$	Look at goal and object area for finalizing status of objects as per the requirements of the goal.	Thinking action	1080
l_{10}	Look at object area and simultaneously perform O^{α}_{61} and O^{ε}_{62}	Decision making for finalization of task completion	370
O^{α}_{60}	Look at object area and simultaneously perform O^{ε}_{62}	Simultaneous perceptual action with motor action	
O^{ε}_{61}	Move cursor to finish button.	Simple motor action.	
O^{α}_{62}	Continue looking at object area and simultaneously perform O^{ε}_{64}	Simultaneous perceptual action with motor action	370
O^{ε}_{63}	Click finish for feedback	Simple motor action.	
O^{α}_{64}	Look at feedback area (area showing error).	Simultaneous perceptual action	360
$O^{\alpha th}_{65}$	Evaluate error information	Thinking action	660
$O^{\alpha th}_{67}$	Look at object area to detect source of error and evaluate error.	Thinking action	750
O^{α}_{68}	Look at goal area	Simultaneous perceptual action	400
O^{α}_{69}	Look at object area and simultaneously perform O^{ε}_{70}	Simultaneous perceptual action with motor action	370
O^{ε}_{70}	Click object element O_S	Simple motor action.	
O^{α}_{71}	Continue looking at tool area and simultaneously perform O^{ε}_{72}	Simultaneous perceptual action with motor action	370
O^{ε}_{72}	Click strike to remove effect.	Simple motor action.	
O^{α}_{73}	Look at object area and simultaneously perform O^{ε}_{74}	Simultaneous perceptual action with motor action	430
O^{ε}_{74}	Click tool underline	Simple motor action.	
O^{α}_{75}	Look at object area and simultaneously perform O^{ε}_{76} .	Simultaneous perceptual action with motor action	510
O^{ε}_{76}	Click OK to complete trial.	Simple motor action.	

5.5.4 Benefits Of The Algorithm

The algorithm presented in Table 5.13 can be studied for improvement of the task sequence and hence the strategy used by the users. In this case, for example take a look at algorithm O_{18}^{ε} and O_{22}^{ε}. The algorithmic is developed on the basis of qualitative logical analysis of the user performance as well as the time used by users for performing different actions and the gaze duration and movement times. Both these algorithms are related to the selection of the element O_Q. But the algorithm is performed at two different stages in the sequence. This results in the fact that the user performs the same algorithm repeatedly to accomplish the same task. All the algorithms following these two selection or perceptual actions with motor action based algorithms could have been done with one single algorithm followed by the sequence of all the other algorithm elements ***(Oa19, l5, Oa20 and Oa21).*** Then consider algorithm ***Oe28***. This is once again a repetition of the algorithm element *Oe5*. Hence, all the algorithm elements after ***Oe28*** can be done after ***Oa17*** once the position of the element O_D is changed to the desired location. This does not violate the sequence reduces the number of mental actions required for the subjects to carry out the operation.

Examining the algorithm on this basis can help remove a major number of elements and complete the task using a smaller number of algorithms. It can be observed that the users associate quite a lot of time in thinking actions. It is not the total cumulative duration of the thinking actions which is important but the average times required to focus in each thinking action. In this case, the thinking actions can be first approached to understand any difficulty the users are facing. For example, the initial stage of the task shows a high increase in the number of thinking actions due to the comparison of the task and the goal elements. However, at the later stage of the task these thinking action durations are quite low. Hence, it can be suggested that using cues and instructions at the initial stage of the task performance can reduce the thinking actions. It should be noted that the use of cues requires the additional burden of understanding the instructions. However, the complexity of the total task may be reduced although the time may increase.

Perceptual actions are the most difficult to reduce in this case as they first of all are the lowest complexity ones and are required for the understanding of the changes the user is imparting on the features of the different task elements. However, in case of simultaneous perceptual actions, the mouse movement or the motor action are also included in the algorithm. This may provide sources of difficulty when the users face problems with the interface in terms of accessing the elements (for example, when the elements are very small) or when using unknown elements associated with the task situation (that is when the context of the task is new and the tool required to perform the exact operation has to be based on decision making than based on mere perceptual processes).

It can be observed that the algorithm mentioned here is from the final phase of the experiment. This means that the user is performing the task at his / her best level and he /she has already gained familiarity of the interface in terms of the elements and the actions required to perform the task satisfactorily. The perfect algorithm in this case is not achieved by any of the users. Describing the algorithm of all the users is beyond the scope of this thesis. However, it was observed that most of the users did not approach the perfect algorithm which can be predicted by using the least number of mouse actions (clicks) as well as the least number of visits by the eye.

Subjective criteria of success during human-computer tasks guide the assessment of complexity of the task by the user. Hence, during objective experimentation and formalized procedures to develop the complexity of the task, it is very important to take into account the subjective criteria of success. In addition, the perfect algorithm may not be achieved due to the fact that subjectively may have more complexity for the user than the one he uses during the performance of the task. User interface design may be attributed to the design of computer interfaces for reducing the cognitive overload on the users by satisfactory interaction design. However, it is critically important to provide appropriate consideration to the fact that users may be accustomed to different modes of task performances, which can have varying results on the estimation of usability as well as identification of the design features for further design consideration. The solution is to study representative algorithms and develop the complexities of these representative algorithms so that alternative design solutions may be arrived at. Based on this the alternative design solutions can be used to create the best possible design addressing a variety of users as well as usage styles, thereby developing what is known as the "ideal algorithm" or the "optimal algorithm" rather than the perfect algorithm.

5.5.5 Evaluating Task Complexity Of A Computer Based Task

Task complexity evaluations are based on the assumption that the more complex a task is, the higher the probability that it will be difficult for a performer and will increase errors. Complexity is an objective characteristic of a task. The difficulty is a subjective evaluation of task complexity. The more complex the task is, the greater the probability will be that it will be difficult for a user to perform (Bedny & Meister, 1997).

The more important problem of task complexity evaluation is the correct selection of units of measures. The quantitative method of task complexity evaluation requires choosing units of measures that permit a comparison of different elements of activity. In other words, it is necessary to transfer different elements of activity into one plane of measurements. Activity is a multi dimensional system and hence multiple measures should be used for evaluation of task complexity. Typical elements of activity (psychological units of analysis) rather than task elements (technological units of analysis) should be used as units of measure. Activity is a process, and the interval of time devoted to different components of activity should be used as units of measures. Any quantitative measures of complexity should reflect the possibility of simultaneous and sequential performance of elements of activity and their probability of occurrence (for more details see Bedny & Meister, 1997; Bedny & Karwowski, 2001).

1) Time intervals for motions requiring a lower (A), average (B), or higher (C) level of concentration of attention can be related to the first, second, and third categories of complexity.

2) If two actions are performed simultaneously and one requires high level concentration of attention (third category of complexity) and the second requires average level of concentration of attention (the second category of complexity) or the first category of complexity (low level of concentration of attention), the complexity of time interval for this simultaneous elements of activity is determined by the complexity of the more difficult element (other rule can be found in Bedny, Meister, 1997).

Using these assumptions complexity of the computer task can be obtained by finding out which type of actions are contained in the algorithms. Also, existence a higher number of mental actions of the third category of complexity may increase the total complexity of the task. The algorithm on the basis of this evaluation can indicate which interface elements and their relations to task are not comfortably accepted by the users and suggest immediate improvement.

5.5.6 Discussion

Most studies in cognitive psychology using eye movements follow a parametric method by obtaining and qualifying eye movement data as dwell time, gaze durations, scan path characterizations, etc. However, this data are not sufficient for description and analysis of a multidimensional system of activity. Hence, eye movement data analysis and interpretation sometimes becomes difficult. Parametric methods of eye movement analysis in activity theory are usually combined with systemic principles of analysis in which eye movements are associated with actions performed by the subject and task performance as a whole. This gives an opportunity to describe the structure of activity. The structure of activity can be considered as a system of logically organized cognitive and motor actions that can contribute to the achievement of the task goal. As a result, cognitive strategies of task performance can be clearly described.

The algorithmic description given in Table 5.13 represents the complete activity structure for the task performed by the subject. Note that individual algorithms can be deduced based on the eye and mouse movement analysis of respective subjects. To reduce this tedious process only a representative subject is taken and the algorithm for the subject is devised. Developing algorithms for the same representative subject provides those actions, which were reduced as the subject goes through repetitive tasks. The analysis of different algorithms and comparative evaluation of design features is beyond the scope of this dissertation. However, the algorithms give a fair idea of human performance for a particular situation. In cases where existing designs need to be evaluated for changes, this represents the ideal solution to comprehensively analyze for faults in the existing design.

For example the first few algorithm elements are mostly thinking and perceptual actions ($O_2^{\alpha th}$ and O_1^{α}). It can be observed that initially there is no mouse movement taking place. Even if there is mouse movement, the movements are not specific towards a target. Here O_4^{ε} only moves the cursor closer to the object area as the subject only has the notion of manipulating them but not the strategy by which he/she is going to do it. Hence, most of the actions in this case are involved in visual perception and understanding of the goal as well as the acceptance of the desired goal. As soon as the subject starts the motor actions the mouse movements become more coordinated with the eye movements. This can be observed by the simultaneous motor actions along with the perceptual actions. O_{13}^{α} and O_{14}^{ε} are performed simultaneously. Most of the algorithms following this execution phase involve simultaneous motor and perceptual actions. However, towards the end, mouse movements are not used during evaluations of the task situation.

The advantage of obtaining the algorithm for human performance is multifold. First the algorithm can be studied to find inefficient user actions that are performed due to lower usability. It also provides the ability to separate errors by users from errors due to the interface. In addition, it also gives the amount of gaze duration involved in the detection of error as well as the excess eye movement and time involved during error detection. This can be used to improve the task, the interface, and the training modules for the users.

The study of the algorithm also provides the sequence of the different mental and motor actions executed by the users during task performance. This can be used to derive the complexity of the task. For example, the amount of time involved only for afferent actions (like the simultaneous perceptual actions) as a percentage of the total time provides the complexity ratio for the perceptual actions during the task. Similarly, the time involved in the thinking actions can be assigned to the standardized level of cognitive complexity and studied.

The overall complexity measure can be thus obtained for the actual performance of the task as well as the ideal performance. This can determine how much the interface deviated is from its achievable usability level for a set of particular tasks. The concept of achievable usability level is new and is quite relative. It is sensitive to design changes and should be exercised with caution in design and training. Studying the algorithms provides a clue as to how the motor and the cognitive actions are intricately dependent on each other.

5.6 General Discussion

Table 5.14 shows the final status of the experimental hypotheses for the different measures, which were used to study the effect of task sequence requirement and the display structure relationship on the dependent variables of interest.

It can be observed that regular measures of usability like efficiency lose their sensitivity as soon as the users learn the task sequence requirement. As a result, evidence in support of hypotheses HA is strong but only at the initial phases of learning. However, as the subjects gain familiarity with the interface and the task, the task and interface relationship does not affect the click efficiency or as a matter of fact the efficiency of performance.

On the other hand, mouse traversal only showed a reduction as the learning occurred. This result provided evidence that motor performance is affected only as the familiarity with the interface details is gradually obtained. Also, there may be an indirect effect of the search efficiency indicated by the number of visits. The number of visits was reduced as learning occurred. This is evident from the main effect of phase on the number of visits. It suggests that movement times and the rate of mouse traversal is affected by the cognitive overload at the initial phases when the subjects are learning the interface and the task. Once they are comfortable, their speed increases.

Table 5.14 Final Status Of Research And Experimental Hypotheses As Per Dependent And Independent Variables Of Interest

Research Hypotheses	Dependent Variable of Interest	Measure	Independent Variable	Experimental Null Hypotheses	Acceptance (significance of 0.05)
HA (Section 5.2)	Performance	Click Efficiency (E)	Compatibility	$HA1_0$	Accepted
			Tool Arrangement	$HA2_0$	Accepted
			Phase of Learning	$HA3_0$	**Rejected**
			Compatibility X Phase of Learning	$HA4_0$	**Rejected**
HB (Section 5.3)	Motor Response	Mouse Traversal Rate (MT)	Compatibility	$HB1_0$	Accepted
			Tool Arrangement	$HB2_0$	Accepted
			Phase of Learning	$HB3_0$	**Rejected**
HC (Section 5.4)	Search efficiency	Number of Eye Visits* (V)	Compatibility	$HC1_0$	Accepted
			Tool Arrangement	$HC2_0$	Accepted
			Phase of Learning	$HC3_0$	**Rejected**
		Average Processing time per visit* (tv)	Compatibility	$HC4_0$	**Rejected**
			Compatibility X Tool Arrangement	$HC5_0$	Accepted
			Phase of Learning	$HC6_0$	Accepted
			Compatibility X Phase of Learning	$HC7_0$	Accepted

Note: Compatibility refers to the relationship between task sequence requirement and display structure
Tool Arrangement refers to the display structure of tools
Phase of learning refers to the learning of the subjects across trials

* Data for the measure required transformation

CHAPTER 6

CONCLUSIONS

6.1 Contributions

It has been observed that today the *user interface* is often the single most important factor in the success of a software project, as it has been estimated that between approximately 50% and 80% of all source code developed is concerned with it (Myers & Rosson, 1992). Since application constraints play a key role in developing interfaces and task structures, it is imperative that the implementation of task sequences, their relationships with the interface display and associated features (structure, hierarchy) be taken into account. The study addressed usability issues already studied in the light of user performance, but uses additional methods (eye tracking and event logging), which have recently been embraced by the usability community. In summary, the contributions of this research are as follows.

- Development of a methodology for identifying areas of interest on the interface based on the task as an object of study. The relevant areas are tool, goal, and object, the notions of which are based on the theoretical understanding of task from Activity Theory principles.
- Development of a set of eye and mouse movement based measures and subsequent investigation of ideal task interface relationships affecting usability of graphical user interfaces.
- The efficacy of eye movements in task based usability evaluations features based on task interface relationships affecting interface quality level were demonstrated.
- Finally using this methodology, eye and mouse movements were used to study human computer interactions using a systemic-structural framework and a human performance model was developed.

6.2 Limitations

This study has various limitations. First, the use of an experimental task was mandatory to control influences on the performance and reduce individual differences due to assessment of task difficulty as well as previous knowledge of the task. It would be worthwhile to observe eye mouse relationships under practical situations and how these relationships are affected.

Second, the eye movement equipment used was not the top of the line equipment used today for most studies. Accurate measurement of the time values of eye and mouse movement relationship data could be obtained if high-end eye movement equipment, which is noninvasive, is used. This would make it possible to study individual elements of the tool area and their influence on user performance in the task sequence.

Third, the subject population represented only few representatives from the age group of above 40 years. A more homogenous mix of subjects would have provided a better understanding of the general consumer expectation of task constraints and the influence of the constraints on task performance.

Finally, spatial relationships and the spatial measures of eye and mouse movements were not studied. This can be the subject of future research. However, the limitation of the equipment precluded the study of exact spatial relationships for individual interface elements. In addition, different resolutions forced the normalization of coordinates to associate eye movement data to different areas of interest in developing the model of human performance. This can result in errors when it comes to smaller areas of interest. The problem was avoided by using larger areas of interest but in actual situations this may not be the case.

6.3 Future Research

The study only used display structure as a factor for providing the task requirement cue to the users so that they can develop the task model. Various other methods, such as hierarchy of functions, menus, multiple window layouts, viability and acceptability of wizards can be studied using the same concept. It is not imperative that eye tracking be applied to the studies. However, its inclusion can provide additional insights.

The extension of systemic-structural framework using the results obtained form this study can be used as a basis to study human computer interactions and evaluate user interfaces based on task performance of the subject. The algorithm of performance developed can be studied for inefficient methods of operation and their association to the functionally relevant areas can be used to understand the problem source.

Understanding the influence of learning on eye and mouse movement relationships for different interface features (grouping, multiple windows, themes, navigation etc) affecting task performance can be investigated. Regularly used task interface relationships may be utilized and investigated on a similar basis as this study.

The understanding of the eye and mouse movement relationships in other task situations for user interfaces can provide clues towards the use of mouse movements as an approximate predictor of eye movements. The results also indicate the possibility of using theoretical frameworks for usability analysis using walkthrough approaches. This is possible due to the fact that since mouse actions are related to the attention shifts of the users, experts can use this knowledge to not only investigate the flow of interaction and the limitations, but also in identifying those interactions which will be best learnt by the subjects.

This study supplements the host of studies done in the eye movement field, but interprets eye movements in a completely different approach using systemic-structural theory of activity. As a consequence, it uses mouse movements and actions to not only interpret searching, selection, actions and comparison, but also use the mouse actions to understand logically the reason behind those movements. The study only has scratched the surface in regards to the potential of Systemic–Structural Theory of Activity.

In the end, it can be observed that a simple eye and mouse movements that are regular phenomenon can be transformed to a vast area of research. Research with individual focus on eye and mouse movements has been vastly appreciated in the past decade. Eye movements have been used for understanding search, confirmation of selections, etc. Mouse movements have been not received so much attention. In the course of the course it was observed that, the relationship of eye and mouse movements and their use to understand human task performance presents a promising area of study. Hence their relationship is worth much more attention.

APPENDIX A

EXPERIMENT DETAILS

A.1 Interface Screen Shots, Specifications And Experimental Tasks

Figure A.1 shows the welcome screen for the subjects at the start of the experiment. The experimenter provides the subject ID and the experiment ID. The experiment ID value determines which interface the subject is supposed to interact with. Experiment ID = 1 is compatible from top, experiment ID = 4 is compatible from bottom, ID = 3 incompatible from top and ID = 2 incompatible from bottom.

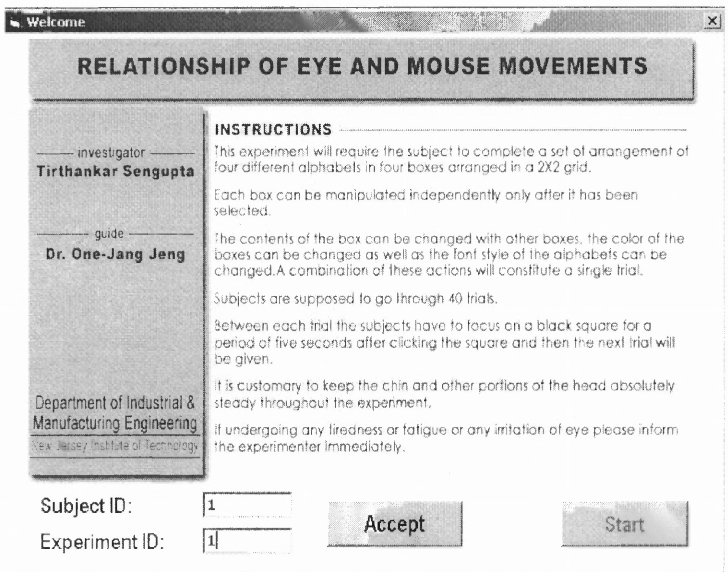


Figure A.1 Screenshot of welcome form for the experiment.

Figure A.2 shows the interface screen for equipment calibration. The subject puts the chin on the chin rest and the experimenter calibrates the equipment to obtain the point of regard on the video of the scene monitor. A five-point calibration is used in this regard for obtaining a steady point on the four corners of the screen.

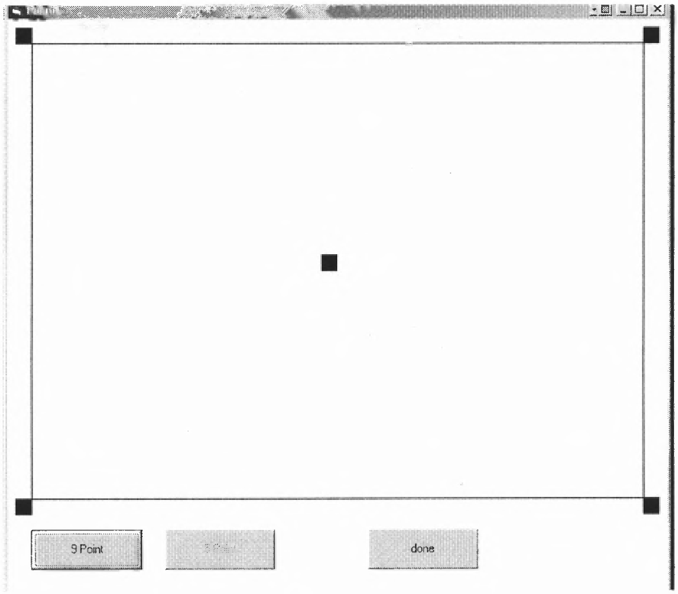


Figure A.2 Screenshot for calibration form for the experiment.

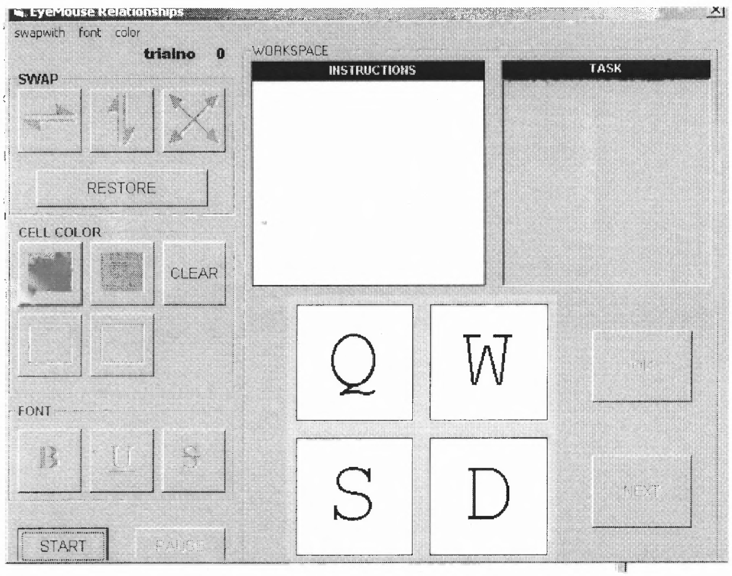


Figure A.3 Screenshot for experimental interface state before start of experiment.

Figure A.3 shows the initial screen before the experiment starts. This is the time at which the experimenter is supposed to explain the interface, the elements on the interface and give instructions to the subject. After the subject is comfortable, the experimenter clicks the start button to explain the highlighted icons as shown in Figure A.4. In this screen the functions of the icons are actually shown to the subject by the experimenter so that he/she has a fair idea of how to run the interface elements. However, the subject is only informed about the existence of the task sequence requirement but is not given the knowledge of the exact sequence. The subject is also instructed to understand the sequence from the trials performed during the course of the experimental set. The eye movement recording starts and the time on the video monitor is noted.

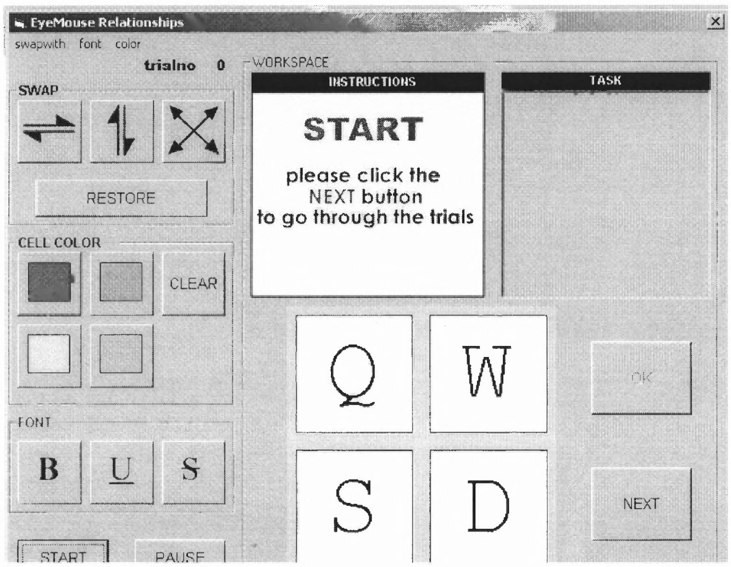


Figure A.4 Screenshot for experimental interface state after start of experiment.

Figure A.5 shows the interface screen during a trial while Figure A.6 shows the screen between two trials. The screen shows a square inside the form located at the center. The subject is supposed to click on this square and continue gazing at this point till a white dot appears on the screen. This is to just ensure that there is no drift in calibration over a period of time. The use of this technique is sufficient to guarantee the data accuracy needed for the study since the areas of interest used in this experiment are quite large.

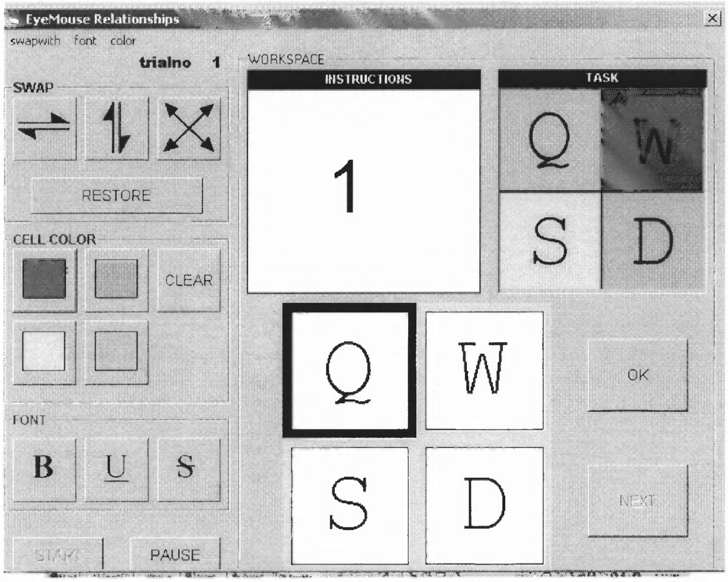


Figure A.5 Screenshot for experimental interface state during trials.

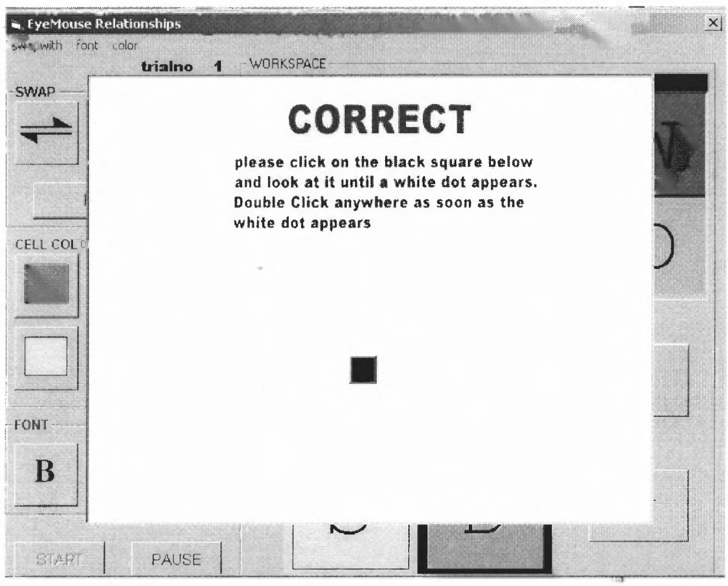


Figure A.6 Screenshot for experimental interface state in between two trials, the center black square checking for calibration.

Figure A.7 show the photographs of the Vision Research lab where the Eye tracking Equipment is calibrated for the subject and Figure A.8 shows the Eye monitor and the scene monitor along with the VCR used for recording the video of the scene monitor.

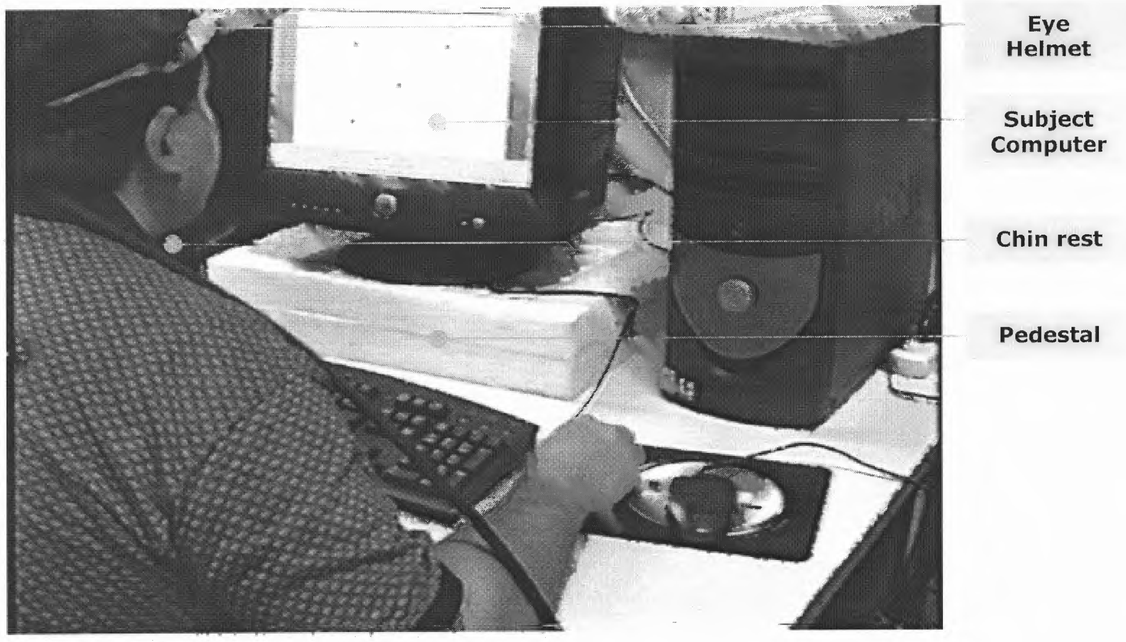


Figure A.7 Calibrating the Eye Tracking Equipment.

Figure A.8 The eye, the scene monitor and the VCR for recording point of regard data.

Table A.1 Tools To Perform Tasks And Intended Operation

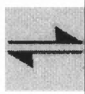
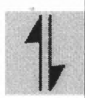
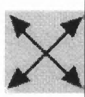
No	Initial	Selection	Identified as	final	Remarks
1	Q	bold	**B**	**Q**	Converts the text in the selected cell to **bold** format
2	Q	underline	U	Q	Converts the text in the selected cell to underline format
3	Q	Strike-through	~~S~~	~~Q~~	Converts the text in the selected cell to ~~strikethrough~~ format
4	Q	red		Q	Converts the cell color to red
5	Q	green		Q	Converts the cell color to green
6	Q	yellow		Q	Converts the cell color to yellow
7	Q	cyan		Q	Converts the cell color to cyan
8	Q W	Swap horizontal		W Q	Switches the position of the selected cell with that on the left/right depending on the cell which is selected
9	Q W	Swap Vertical		W Q	Switches the position of the selected cell with that on the top/bottom depending on the cell which is selected
10	Q W	Swap diagonal		W Q	Switches the position of the selected cell with that diagonally opposite depending on the cell which is selected
11		Reset			Restores the cell positions to the initial state
12		Clear			Clears the cells of any colors
13		Start			Start the states/ experiments
		OK			Subject should click this button when convinced about the exact matching of the given arrangement and the arrangement they have obtained through the use of the tools previously described.
14		Next			To proceed to the next trial. Will not be activated unless the subject correctly does the current one. Stops mouse movement recording
15		Pause/ Resume			Pause any time between the end of one trial and before clicking next. Starts mouse movement recording

Table A.2 Goals Given To Users (1-12 and 13-24: learning: 25-40 experimental)

Goal	Representation	Goal	Representation	Goal	Representation	Goal	Representation
1	D S / Q W	11	Q W / S D	21	S D / Q W	**31**	D S / Q W
2	Q W / S D	12	Q W / S D	22	S D / Q W	**32**	D S / Q W
3	Q W / S D	13	W S / D Q	23	W Q / D S	**33**	D S / Q W
4	W Q / D S	14	D S / W Q	24	W D / S Q	**34**	S W / D Q
5	W Q / D S	15	W D / Q S	**25**	D Q / S W	**35**	W Q / D S
6	Q W / S D	16	Q S / W D	**26**	S Q / D W	**36**	W Q / D S
7	W Q / S D	17	D S / Q W	**27**	D W / Q S	**37**	W Q / D S
8	D Q / W S	18	D S / Q W	**28**	Q D / S W	**38**	D W / Q S
9	Q W / S D	19	W S / Q D	**29**	Q D / W S	**39**	W Q / S D
10	Q W / S D	20	Q S / W D	**30**	W D / Q S	**40**	W Q / S D

A.2 Pilot Study

The pilot study was conducted for various purposes. These are as follows.

1. To understand the preference of the users in terms of the functions of the interface, so that the task interface requirement violations can be manipulated by the experimenter to observe the effects.
2. To understand whether the subjects will provide any preference of the sequence of the letters due to their position on the alphabet sequence.
3. To estimate the relative stability of the video data in terms of the calibration so that the eye visit and the average processing time data can be approximately collected fairly.

Table A.3 Pilot Study Results

	Sequence	Letter sequence followed	Interface used
Subject 1	Position first then color and format together	random	From top, no sequence
Subject 2	Position first then color then format	First a then b then c then d	
Subject 3	Position first, color and format in any order	random	
Subject 4	Position then color then format	Top left , top right, bottom left, bottom right	
Subject 5	Position then color then format	random	

Note: The pilot study was performed with the letters a, b, c, d and in the experiment the letters were changed to Q,W,S,D.

APPENDIX B

PERMITS, CONSENT FORMS AND QUESTIONNAIRE

B.1 Human Subject Review Application

PLEASE PRINT OR TYPE

Date:________08/12/2002____________________ Project Number:_____________________________

HUMAN SUBJECT RESEARCH REVIEW FORM (A)
NJIT INSTITUTIONAL REVIEW BOARD

Name:___Tirthankar Sengupta

NJIT Address:____GITC Rm 2309, University Heights______________________

____Newark, NJ 07102-1982____

Department::_______________Industrial and Manufacturing Engineering________________________________

NJIT Affiliation (Check all that apply)

Faculty	________	Research Associate	________
U/G Student	________	Doctoral Candidate	_____X_____
Graduate Student	________	Post Doctoral	________
Other	________		

Project Title: Relationship of eye and mouse movements- The effects of interface and the task.

This project will be conducted:

On Campus	____X_______	Off Campus	____________
Both	________		

Anticipated Sponsor (s) of this project:

NJIT	______X_____	Government	________
Foundation	________	Federal	________
Organization	________	State	________

Starting Date of Project:_________09/10/02________________

Closing Date of Project: 10/05/02

To Principal Investigator: In addition to the questions below, please furnish copies of any questionnaires interview formats, testing instruments or other documents necessary to carry out the research.

The completed forms should be sent to: Richard Greene, M.D., Ph.D
Chair of Institution Review Board
Biomedical Engineering
New Jersey Institute of Technology
University Heights
Newark, NJ 07102-1982

1. Project Title:
Relationship of eye and mouse movements- the effects of interface and the task.

2. List the name and the Faculty/Student/Staff status of the persons conducting the research:

a. **Principal Investigator: Tirthankar Sengupta**

b. **Co-Principal Investigator: Dr. One-Jang Jeng**

3. Attach copy of permission of facility to conduct the proposed research (if other that NJIT).

Please see Attachment # 1

3. In a few words (100 or less) describe the objectives, methods and procedures of the research projects. This summary will used to describe your project to the committee on Human Subjects.

This study will objectively record eye movements in people performing a computer-based task on an interface designed to perform the task. The subjects will go through 20 to 30 minute sessions with voluntary breaks. Mouse movements of the subjects will be recorded through the software. The only eye movement data recorded in this case is the point of regard (POR), which is the location of the point of attention by the subjects on the computer screen. Subjects will be using a chinrest throughout the task. However, they are allowed to blink and do other normal physiological operations. The subjects will first go through a questionnaire. Then they will be calibrated for the screen and asked to do the task. Once they are calibrated subjects will not be allowed to move the chin from the chin rest. In case a break is asked the subjects will be recalibrated and asked to continue with the task.

The objective of the study is to assess the relationship of eye and mouse movements based on statistical analysis of the eye and mouse coordinates throughout the experiment. The study also will investigate the effects of the type of task and the interface parameters on the eye mouse paths as well as the performance. The basic aim is to investigate the possibility of existing relationships of eye and mouse movements and how these relationships are affected due to task and interface differences.

4. List name and institutional affiliation of any research assistants, workers student that will be working on this project.

The project is aimed at the partial requirement for completion of Doctoral Desertation in Industrial Engineering with Human Factors Concentration of Tirthankar Sengupta of the department of Industrial and Manufacturing Engineering.

5. If research assistants, workers, students will be working on the project describe their qualifications, special training and how they will be supervised.

The PhD candidate working on this project will be under the supervision of Dr. One-Jang Jeng, Department of Industrial and Manufacturing Engineering, NJIT.

6. What is the age of the subjects and how will they be recruited?

There will be no restriction on the gender. However subjects with age between 18 and 55 will be considered while recruiting. Subjects should also have a fair knowledge of computers and regular users of software applications like word processors and spreadsheets. Students and faculty from the New Jersey Institute of technology will be recruited to perform the task. The subjects will be paid a basic amount and an additional amount based on their performance. Which is measured on the basis of efficiency and correctness of performance of the tasks.

7. Attendant risks: Indicate any physical. psychological, social or privacy risk or pain, which may be incurred by human subjects, or any drugs medical procedures that will be used. (This includes any request for the subjects to reveal any embarrassing, sensitive, or confidential information about themselves or others.) Also, indicate if any deception will be used, and if so, describe it in detail. Include your plans for debriefing.

The objective eye movement recordings are noninvasive utilizing infrared light. Subjects will wear a head mounted eye movement monitor during experiments. The subject indicates they are ready by clicking a particular button on the software. After the button is pressed the tasks will be performed with the chin fixed to the chinrest. After each successful completion of trial the data will be saved in a text file. Subjects can take a break any time and perform all the normal physiological operations of the eye. Hence no drying of the sclera or other situations that occur in eye movement experiments will not be encountered. Based on pilot studies without the eye tracker it is estimated that total experiment will take around 30 min.

The RK 726 PCI Eye Tracking system from ISCAN eye tracking laboratories mentions two potential concerns for safety with (infra-Red) LED illuminator used to detect the point of regard of the subjects. The radiant output for the IR LED is around 1.2 mW/cm2 whereas the safety standard for OSHA is 10 mW/cm2. ISCAN claims that the exposure is around 12% of the OSHA levels. As to thermal levels the exposure is around 6%. The certificate is attached with the document.

Please see attachment # 2

8.Evaluate the risks presented in 7.
a. Is it more that would normally be encountered in daily life?

The only risk that is associated with the experiment is the exposure of the eye to the infrared light, which according to the manufacturer falls well below the upper bound levels of the amount of radiation that can be sustained by the human subject. The additional risk may be due to fatigue for maintaining the chin at the same position, which can be mitigated through use of rest breaks.

b. Do your procedures follow established and accepted methods in your field?

Yes.

9.How will the risk be kept at a minimum? (e.g. describe how the procedures reflect respect for privacy, feeling, and dignity of subject and avoid unwarranted invasion of privacy or disregard anonymity in any way.) Also, if subjects will be asked to reveal any

embarrassing, sensitive, or confidential information, how will confidentiality of the data be insured? Also include your pans for debriefing. If subjects will be placed under any physical risk, describe the appropriate medical support procedures.

Risks will be kept to a minimum by using a non-invasive eye movement monitor. Identification will be by subject initials and age and gender will be recorded. The procedures do not reveal information that is an invasion of privacy. Subjects will be debriefed before the experiment by explaining experimental protocol as noted above and asked to undergo practice trials by using the same interface they would for the actual experiment. Above all, the subjects can discontinue the experiment if they experience any discomfort.

10.Describe the benefits to be derived from this research, both by the subject and by the scientific community (this is especially important if research involves children).

The study provides the human computer interaction research community with a detailed insight of eye and mouse movement relations. It also caters to the issues regarding the effect of task and interface on these physiological outputs. Interface design issues can be addressed more effectively based on the findings. Till now the focus has been the user. But here we enter a dynamic situation where the relationship of the user with the task and the interface is established for better interaction design.

11.Describe the means through which human subjects will be informed of their right to participate, not to participate, or withdraw at any time. Indicate whether subjects will be adequately informed about the procedures of the experiment so that they can make an informed decision on whether or not to participate.

The subjects will be given a complete instruction for running the application to perform the task. Before filling the questionnaire they will be asked to go through the instructions and the consent form. The subjects will be mentioned about the objectives and procedure of the experiment. The subjects may wish to see their results after the experiment. After the completion of the experiment the subjects will be debriefed on their performance as well as all the aspects of the experiment and how the results will be used. The subjects may wish to withdraw before filling up the questionnaire if they decide not to continue.

12. Complete the attached copy of the Consent Form and the Institutional Review Board will make a determination if your subjects will be at risk. This Consent Form must include the following five pieces of information: (1) The purpose of the research, (2) the procedures involved in the work, (3) the potential risk of participating, (4) the benefits of the research, (5) that the subjects are free to withdraw from the research at any time with no adverse consequences.

Furnished in this document.

13. Furnish copies of questionnaires, interview formats, testing instruments or other documents to carry out the research. If questionnaires are not complete please submit an outline of the questions to be used. You will have to submit the completed questionnaire to the Committee before the research can begin.

Please see Attachment # 3

14.If the subjects will be minor children, complete Consent Form as prescribed in paragraph 12 for signature by parent or guardian. If the project is approved (regardless of the Board's determination concerning risk), it will be necessary that a Consent Form be secured for every minor child.

Not Applicable

B.2 Institutional Review Board Approval

IRB Project Number
C5-04

New Jersey Institute of Technology

HUMAN SUBJECTS REVIEW FORM FOR PERIODIC REVIEW

Fill out the form *completely*. Periodic Review cannot be accomplished unless the progress report is completed, a copy of the current consent form is included, and appropriate signatures are obtained. Incomplete forms will be returned.

PRINCIPAL INVESTIGATOR (S): **Tirthankar Sengupta**

CO-INVESTIGATOR (S): **Dr. One-Jang Jeng**

FACULTY SPONSOR, if applicable: **Dr. One-Jang Jeng**

SCHOOL: **Newark College of Engineering** DEPARTMENT/SECTION: **Industrial Engineering**

PROJECT TITLE: **INVESTIGATING GRAPHICAL USER INTERFACE USABILITY ON TASK SEQUENCE AND DISPLAY STRUCTURE DEPENDENCIES**

FUNDING AGENCY OR RESEARCH SPONSOR: **Dept of Industrial And Manufacturing Engg.**

PRINCIPAL INVESTIGATOR'S INFORMATION:
Mailing Address: **32 Washington Street, 2nd Floor, Harrison NJ 07029**
E-Mail Address: **tirthank@yahoo.com, t_sengupta@hotmail.com** Telephone Number: **862-755-6081**
Fax Number: **973-596-3652**

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The project was **LAST APPROVED** on **09/15/2003** A **PERIODIC REVIEW** is scheduled for **10/30/2003**

....

I. PROJECT DESCRIPTION

A. Project activity STATUS is (check one of four boxes, as appropriate):

☒ **CONTINUING** with **NO CHANGES** in procedure, risks, or class of human subjects since the last review.

☐ **REVISED**. Minor changes may be indicated on this form. For substantial changes, a new Human Subjects Review Form must be completed, indicating the manner in which the project was revised, and returned with this form. Please complete this form also.

☐ **NEVER INITIATED. WORK WILL NOT BE DONE AT THIS TIME.** Please sign on page three and return this form through the appropriate offices for signature.

☐ **COMPLETED. NO FURTHER CONTACT WITH HUMAN SUBJECTS IS PLANNED.** Please sign on page three and return this form through the appropriate offices for signature.

B. This project will be conducted at the following SITE (S):

☒ NJIT

☐ UMDNJ - Newark

☐ OTHER (specify):

____

II. PROGRESS REPORT

A. NUMBER OF SUBJECTS STUDIED TO DATE: **40**

NUMBER OF SUBJECTS STUDIED SINCE THE LAST REVIEW: **40**

NUMBER OF SUBJECTS YET TO BE STUDIED: **based on review with dissertation committee**

B. Have any ADVERSE REACTIONS been noted since the last review?

☐ YES ☒ NO If YES, how many?

Were any of these UNANTICIPATED REACTIONS? ("Unanticipated" being defined as not having been anticipated in the protocol nor stated in the consent form)

☐ YES ☒ NO

If you have answered YES to either of the above, please attach an explanation.

C. Provide a STATEMENT regarding the STATUS of any DRUGS, BIOLOGICS or DEVICES employed in the study.

None of the above mentioned agents were employed as a treatment to the subjects during the study.

D. SUMMARY OF RESULTS to date:

- **50 subjects have been studied for the experiment.**
- **The results are now under analysis for the various outcomes and study of the treatment effects that were observed.**

- **Based on the outcomes of the research a presentation is scheduled for the end of the semester (Fall 2003).**
- **Further study on subjects will be based on the outcome of the meeting.**
- **There will be no changes in the procedure described earlier.**

E. Please attach a copy of your **CURRENT CONSENT FORM**.
E. Any **ADDITIONAL INFORMATION**, which may be useful to the reviewers.

- **The equipment if further used should not be tested with subjects having contact lenses.**
- **Although there is no after effect of the infrared, continuous focus is required during such an experiment which demands rest breaks every 15 minutes. This value is based on the different subjects request for rest breaks.**

I certify that the approved protocol and approved method for obtaining informed consent have been followed during the period covered by this **PROGRESS REPORT**.

_**10/13/2003**_______ _____**Tirthankar Sengupta**_______________________
Date Principal Investigator

III. INSTITUTIONAL ENDORSEMENTS

Your endorsement is requested to assure the Institutional Review Board that your office is aware of the existence and status of this research activity:

__**10/13/2003** ____ ________**Dr. A. Bladikas**___________________________
Date Department Chairman

....

Submit to:

IRB Office Colton 341 C/o Richard Greene, Chair

IRB Telephone Number (973) 596-3281
IRB FAX Number (973) 596-5222
IRB E-MAIL ADDRESS greener@adm.njit.edu

B.3 Institutional Review Board Approval Update

NJIT NEW JERSEY INSTITUTE OF TECHNOLOGY

Institutional Review Board: HHS FWA 00003246
Notice of Approval
IRB Protocol Number: C5-04

Principal Investigator/Dept: Tirthankar Sengupta/Industrial Engineering

Title: **INVESTIGATING GRAPHICAL USER INTERFACE USABILITY ON TASK SEQUENCE AND DISPLAY STRUCTURE DEPENDENCIES**: NJIT

Sponsor Protocol Number:

Type of Review: FULL [ ] EXPEDITED [X]

Type of Approval: NEW [ ] RENEWAL [X] MINOR REVISION [ ]

Approval Date: March 2, 2004 Expiration Date: March 1, 2005

1. **ADVERSE EVENTS:** Any adverse event(s) or unexpected event(s) that occur in conjunction with this study must be reported to the IRB Office immediately (x3281).
2. **RENEWAL:** Approval is valid until the expiration date on the protocol. You are required to apply to the IRB for a renewal prior to your expiration date for as long as the study is active. Renewal forms will be sent to you; but it is your responsibility to ensure that you receive and submit the renewal in a timely manner.
3. **Consent Form:** All subjects must receive a copy of the consent form; the original signed copy must be kept in a secure place by the principal investigator.
4. **Subjects:** Number of subjects approved: 60.
5. The investigator(s) did not participate in the review, discussion, or vote of this protocol.
6. **APPROVAL IS GRANTED ON THE CONDITION THAT ANY DEVIATION FROM THE PROTOCOL WILL BE SUBMITTED, IN WRITING, TO THE IRB FOR SEPARATE REVIEW AND APPROVAL.**

Richard Greene, M.D., Ph.D., Chair IRB

March 2, 2004
Date

B.4 Consent Form for Subjects

NEW JERSEY INSTITUTE OF TECHNOLOGY
323 MARTIN LUTHER KING BLVD.
NEWARK, NJ 07102

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE OF STUDY:
INVESTIGATING GRAPHICAL USER INTERFACE USABILITY ON TASK SEQUENCE AND DISPLAY STRUCTURE DEPENDENCIES

RESEARCH STUDY:

I,____, have been asked to participate in a research study under the direction of Tirthankar Sengupta. He will be supervised by Dr. One-Jang Jeng of the Industrial and Manufacturing Engineering Department. Other professional persons who work with Dr. Jeng as study staff may assist to act for him.

PURPOSE: To study eye and mouse movements while undertaking a computer based task. The study will monitor my eye and mouse movements while I am working on an interface to carry out a certain task as designed by the instructor.

DURATION:
My participation in this study will last for a maximum of two hours.

PROCEDURES:
I have been told that, during the course of this study, the following will occur:
I will be given a questionnaire, which will ask for my age, gender, occupation and experience with computers, specifically the different types of software.
I will be asked to wear a head-mounted equipment, which will monitor my eye movements. Throughout the experiment my eye and mouse movements will be monitored.
I will have to complete certain tasks on the computer for which I will be given practice trials for proper execution during the experiment.
I will have to keep my heady steady through the use of a chin rest during the experiment.
An infrared light of very low intensity will be projected on my eyes for recording the eye movement.
The computer screen seen through a camera on the head mount will be recorded on a VCR with time code. However, subject will not be seen in the recording.

PARTICIPANTS:

I will be one of about _40 participants to participate in this trial.

EXCLUSIONS:

I will inform the researcher if any of the following apply to me:

I use contact lenses for correcting vision.

RISK/DISCOMFORTS:
I have been told that the study described above may involve the following risks and/or discomforts:
keeping the head steady during the experiment makes me tired.
eyes can very rarely undergo any kind of irritation or tiring.
If I suffer any kind of discomfort during the experiment.
I am entitled to abort the experiment if I suffer any kind of discomfort while performing by reporting to the experimenter.

CONFIDENTIALITY:
Every effort will be made to maintain the confidentiality of my study records. Officials of NJIT will be allowed to inspect sections of my research records related to this study. If the findings from the study are published, I will not be identified by name. My identity will remain confidential unless disclosure is required by law.

PAYMENT FOR PARTICIPATION:
I have been told that I will receive adequate compensation for my participation in this study.

CONSENT AND RELEASE:
I fully recognize that there are risks that I might be exposed to by volunteering in this study which are inherent in participating in any study; I understand that I am not covered by NJIT's insurance policy for any injury or loss I might sustain in the course of participating in the study.
I agree to assume and take on myself all risks and responsibilities in any way associated with this activity. I release NJIT, its trustees, agents, employees and students from any and all liability, claims and actions that may arise as a result of my participation in the study. I understand that this means that I am giving up my right to sue NJIT, its trustees, agents and employees for injuries, damages or losses I may incur.

RIGHT TO REFUSE OR WITHDRAW:
I understand that my participation is voluntary and I may refuse to participate, or may discontinue my participation at any time with no adverse consequence. I also understand that the investigator has the right to withdraw me from the study at any time.

INDIVIDUAL TO CONTACT:
If I have any questions about my treatment or research procedures that I discuss them with the princpal investigator. If I have any addition questions about my rights as a
research subject, I may contact:

Richard Greene, M.D., Ph.D., Chair, IRB (973) 596-3281

SIGNATURE OF PARTICIPANT

I have read this entire form, or it has been read to me, and I understand it completely. All of my questions regarding this form or this study have been answered to my complete satisfaction. I agree to participate in this research study.

Subject: Name:____________________

Signature:__________________________

Date:____________________________

SIGNATURE OF READER/TRANSLATOR IF THE PARTICIPANT DOES NOT READ ENGLISH WELL

The person who has signed above, ____, does not read English well, I read English well and am fluent in (name of the language) ____________________________________, a language the subject understands well. I have translated for the subject the entire content of this form. To the best of my knowledge, the participant understands the content of this form and has had an opportunity to ask questions regarding the consent form and the study, and these questions have been answered to the complete satisfaction of the participant (his/her parent/legal guardian).

Reader/
Translator: Name:______________________

Signature:________________________

Date:_________________________________

SIGNATURE OF INVESTIGATOR OR RESPONSIBLE INDIVIDUAL

To the best of my knowledge, the participant, ____, has understood the entire content of the above consent form, and comprehends the study. The participants and those of his/her parent/legal guardian have been accurately answered to his/her/their complete satisfaction.

Investigator's Name:_____________________ Signature:______________________

Date:___________________________________

B.5 Background Questionnaire

Please indicate your answer in the boxes by printing the option (1,2 etc.) you choose, unless otherwise indicated.

1. What is your age?

[1] > 18 yrs
[2] > 25 yrs
[3] > 40 yrs
[4] > 55 yrs

2. What is your gender?

[1] Male
[2] Female

3. What is your status in school?

[1] Undergraduate Student
[2] Graduate Student
[3] Faculty/Staff
[4] Other

4. How often do you use the computer?

[1] >4 hrs/day
[2] >2 hrs/day
[3] 3-4 times a week
[4] Once or twice a week
[5] Seldom

5. For what kind of activities do you use the computer most often?

[1] Work
[2] Entertainment
[3] Communication (correspondence etc)
[4] Learning (online education/training etc)

6. Which of the following software/application have you used or have knowledge of? (order)

[1] Word Processors (Microsoft Word, Word Pad,)
[2] Spreadsheets (Microsoft Excel, Lotus)
[3] Email (Outlook etc)
[4] The Internet (any web browser)
[5] Other

7. During the last 90 days, how have you used the above-mentioned software? (Frequency and percentage of use put percentage values and make sure total is 100)

_____ % [1] Word Processors
_____ % [2] Spreadsheets
_____ % [3] Email
_____ % [4] The Internet
_____ % [5] Other

8. Do you use computer-assisted services for your regular activities? For example using the ATM or Internet for banking, the ticket vending machines at railway and bus stations and other form of interface oriented services and if so how often?

[1] All the time
[2] Frequently
[3] Sometimes when the manual services are not available
[4] I prefer manual services all the time

9. Which of the following items do you own? Please check all that apply.

- ☐ [1] Portable Digital Assistant (PDA)
- ☐ [2] Laptop Computer
- ☐ [3] Mobile Phone
- ☐ [4] Video/Digital Camera
- ☐ [5] I do not own any of the above

APPENDIX C

CODES FOR EXPERIMENTAL DATA PROCESSING

C1 Code Snippets Used For Data Extraction

All the codes for data processing are in Microsoft Visual Basic ®.

Raw data processing mouse movement

```
Dim a(3) As Long
Dim d(6) As Long
Dim filenm As String
Dim linkdistribarray(18, 18) As Integer
Dim num() As Integer
Dim time() As Long
Dim start As String
Dim flag(40, 40) As String
Dim flag2(40) As String
Dim block1(10) As String
Dim block2(10) As String
Dim block3(10) As String
Dim block4(10) As String
Dim xcor() As Integer
Dim ycor() As Integer
Dim dist() As Long
Dim cudist() As Long
Dim button() As Integer
Dim counter As Integer
Dim counterror As Integer, error As Integer
Dim dur As Long, c As Long
Dim aver As String
Dim i As Integer, j As Integer, k As Integer
Dim n As Long
Dim gazearray() As Integer
Dim sacearray() As Integer
Dim current As Integer, previous As Integer

//sequence and number of clicks
Private Sub Command1_Click()
Open "G:\terry\sequenceanalysis\fullseq" + Text1.Text + ".txt" For Output As #2

filenm = "G:\terry\" + Text1.Text + "\timebetwclicks" + Text1.Text + ".txt"
Open filenm For Input As #1
n = CountLines(filenm)

c = 0
ReDim num(n) As Integer
ReDim time(n) As Long
ReDim button(n) As Integer
Do While Not EOF(1)

        For j = 0 To 2
            Input #1, a(j)
        Next j
        num(c) = a(0)
        time(c) = a(1)
        button(c) = a(2)
        c = c + 1
    Loop
 i = 0

For c = 0 To n - 1
    If num(c) = num(c + 1) Then
```

```
        If button(c) < 4 Then
        flag(num(c) - 1, i) = CStr(button(c))
        End If
        If button(c) > 3 And button(c) < 8 Then
        flag(num(c) - 1, i) = CStr(button(c))
        End If
        If button(c) > 7 And button(c) < 12 Then
        flag(num(c) - 1, i) = CStr(button(c))
        End If
        If button(c) > 11 And button(c) < 20 Then
        flag(num(c) - 1, i) = CStr(button(c))
        End If
        If button(c) = 21 Then
             flag(num(c) - 1, i) = "q"
        End If
        If button(c) = 22 Then
             flag(num(c) - 1, i) = "w"
        End If
        If button(c) = 23 Then
             flag(num(c) - 1, i) = "s"
        End If
        If button(c) = 24 Then
             flag(num(c) - 1, i) = "d"
        End If

        'If button(c) < 25 And button(c) > 0 Then
        'flag(num(c) - 1, i) = button(c)
        'End If
    i = i + 1
    Else
        i = 0
    End If
Next c

For i = 0 To 39
 For j = 0 To 30
  If flag(i, j) = " " Then
  Exit For
  Else
  flag2(i) = flag2(i) + CStr(flag(i, j)) + ","
  End If
Next j

Next i

'print the sequences
For i = 0 To 40
Print #2, flag2(i)
Next i
    Close #1
    Close #2

//array initializing number

End Sub
Function CountLines(ByVal strFilePath As String) As Long

       '     'delcare variables
       Dim fileFile As Integer
       Dim intLinesReadCount As Long
       intLinesReadCount = 0
       '     'open file
       fileFile = FreeFile

Open strFilePath For Input As fileFile

Dim strBuffer As String

              Do While Not EOF(fileFile)
                           'read line
                     Input #fileFile, strBuffer
```

```
                        'update count
                    intLinesReadCount = intLinesReadCount + 1
            Loop

            'close file
        Close fileFile
            'return value
        CountLines = intLinesReadCount
End Function

Private Sub Command11_Click()
' finding out the sequence distance ideal

End Sub

Private Sub Command2_Click()
Open "G:\terry\" + Text1.Text + "\mousedistances" + Text1.Text + ".txt" For Output As #2
Open "G:\terry\" + Text1.Text + "\completiondist" + Text1.Text + ".txt" For Output As #3

filenm = "G:\terry\" + Text1.Text + "\distandcudist" + Text1.Text + ".txt"
Open filenm For Input As #1
n = CountLines(filenm)
c = 0
ReDim num(n) As Integer
ReDim xcor(n) As Integer
ReDim ycor(n) As Integer
ReDim dist(n) As Long
ReDim cudist(n) As Long
ReDim button(n) As Integer
Do While Not EOF(1)

        For j = 0 To 5
            Input #1, d(j)
        Next j
        num(c) = d(0)
        xcor(c) = d(1)
        ycor(c) = d(2)
        dist(c) = d(3)
        cudist(c) = d(4)
        button(c) = d(5)
        c = c + 1
    Loop
    For c = 0 To n - 1
    If c > 0 Then
        If num(c) > num(c - 1) Then
            Print #2, num(c - 1), dist(c - 1), cudist(c - 1)
        End If
        If num(c) = 40 And c = n - 1 Then
            Print #2, num(c), dist(c), cudist(c)
        End If
        If button(c) = 13 Then
            Print #3, num(c), xcor(c), ycor(c), dist(c)
        End If

    End If

    Next c
    Close #1
    Close #2
    Close #3
End Sub

Private Sub Command3_Click()

Open "H:\clickhistory\grouping1" + Text1.Text + ".txt" For Output As #2
'Open "G:\terry\" + Text1.Text + "\mousetimesok" + Text1.Text + ".txt" For Output As #3

filenm = "H:\clickhistory\timebetcl" + Text1.Text + ".txt"
Open filenm For Input As #1
n = CountLines(filenm)
c = 0
```

```
ReDim num(n) As Integer
ReDim time(n) As Long
ReDim button(n) As Integer
Do While Not EOF(1)

        For j = 0 To 2
            Input #1, a(j)
        Next j
        num(c) = a(0)
        time(c) = a(1)
        button(c) = a(2)
        c = c + 1
    Loop
 i = 0
For c = 0 To n - 1
    If num(c) = num(c + 1) Then
        'If button(c) < 4 Then
       ' flag(num(c) - 1, i) = "a"
       ' End If
       ' If button(c) > 3 And button(c) < 8 Then
       ' flag(num(c) - 1, i) = "b"
       ' End If
       ' If button(c) > 7 And button(c) < 12 Then
       ' flag(num(c) - 1, i) = "c"
       ' End If
       ' If button(c) > 11 And button(c) < 20 Then
       ' flag(num(c) - 1, i) = "0"
       ' End If
       ' If button(c) > 20 Then
       ' flag(num(c) - 1, i) = button(c) - 20
       ' End If

    i = i + 1
    Else
        i = 0
    End If
Next c

For i = 0 To 39
    If flag(i, 0) = "1" Or flag(i, 0) = "2" Or flag(i, 0) = "3" Or flag(i, 0) = "4" Then
        block = CInt(flag(i, 0))
        If block = 1 Then
            block1(0) = CStr(block)
        End If
        If block = 2 Then
            block2(0) = CStr(block)
        End If
        If block = 3 Then
            block3(0) = CStr(block)
        End If
        If block = 4 Then
            block4(0) = CStr(block)
        End If

    Else
        block1(0) = "1"
    End If
    k = 1
    For j = 1 To 30
        If flag(i, j) = "" Then
        Exit For
        Else
            If flag(i, j - 1) = "1" Then
                block1(k) = flag(i, j)
            End If
            If flag(i, j - 1) = "2" Then
                block2(k) = flag(i, j)
            End If
            If flag(i, j - 1) = "3" Then
                block3(k) = flag(i, j)
            End If
```

```
            If flag(i, j - 1) = "4" Then
                block4(k) = flag(i, j)
            End If

            k = k + 1
        End If

    Next j
Next i
'print the sequences


For i = 0 To 40
Print #2, flag2(i)
Next i
    Close #1
    Close #2
    'Close #3

'distribution of sequences

End Sub
Private Sub Command5_Click()
Open "H:\clickhistory\sequence" + Text1.Text + ".txt" For Output As #2
Open "H:\clickhistory\startend" + Text1.Text + ".txt" For Output As #3

filenm = "H:\clickhistory\timebetcl" + Text1.Text + ".txt"
Open filenm For Input As #1
n = CountLines(filenm)
c = 0
ReDim num(n) As Integer
ReDim time(n) As Long
ReDim button(n) As Integer
Do While Not EOF(1)

        For j = 0 To 2
            Input #1, a(j)
        Next j
        num(c) = a(0)
        time(c) = a(1)
        If a(2) > 20 Then
        a(2) = a(2) - 7
        End If
        button(c) = a(2)
        c = c + 1
    Loop
    linkdistribarray(12, button(c)) = 1
For c = 1 To n

    linkdistribarray(button(c - 1), button(c)) = linkdistribarray(button(c - 1),
button(c)) + 1

Next c

For i = 0 To 18
    For j = 0 To 18
    If linkdistribarray(i, j) > 0 Then
    Print #2, i, j, linkdistribarray(i, j)
    Print #3, linkdistribarray(i, 0), linkdistribarray(i, 1), linkdistribarray(i, 2),
linkdistribarray(i, 3), linkdistribarray(i, 4), linkdistribarray(i, 5),
linkdistribarray(i, 6), linkdistribarray(i, 7), linkdistribarray(i, 8),
linkdistribarray(i, 9), linkdistribarray(i, 10), linkdistribarray(i, 11),
linkdistribarray(i, 12), linkdistribarray(i, 13), linkdistribarray(i, 14),
linkdistribarray(i, 15), linkdistribarray(i, 16), linkdistribarray(i, 17)
    End If
```

Algorithms for data extractions and analysis

```
Private Sub cmdclicks_Click()
start = 0
swaphor = 0
swapver = 0
swapdiag = 0
Bold = 0
ita = 0
under = 0
strike = 0
red = 0
green = 0
yellow = 0
blue = 0
Next1 = 0
ok = 0
pause = 0
Clear1 = 0
Reset1 = 0
Pict1 = 0
Pict2 = 0
Pict3 = 0
Pict4 = 0
cali = 0

Open "G:\terry\clickall1.txt" For Append As #2
Open "G:\terry\clickall2.txt" For Append As #3
Open "G:\terry\clickall3.txt" For Append As #4

k = 1
For i = 0 To 39
    If i > 11 Then
    k = 2
    End If
    If i > 23 Then
    k = 3
    End If
filenm = "H:\terry\dataforblanchard\" + Text5.Text + "\" + Text6.Text + "\" + Text7.Text
+ CStr(k) + CStr(i) + ".csv"
Open filenm For Input As #1
n = CountLines(filenm)
c = 0
ReDim num(n) As Integer
ReDim xcor(n) As Integer
ReDim ycor(n) As Integer
ReDim time(n) As Long
ReDim button(n) As Integer
    Do While Not EOF(1)

        For j = 0 To 5 '###########3
            Input #1, a(j)
        Next j

        num(c) = a(1)
        xcor(c) = a(2)
        ycor(c) = a(3)
        time(c) = a(4)
        button(c) = a(5)
        c = c + 1

     Loop
    For c = 0 To n - 1
        If button(c) = 1 Then
        swaphorcount = swaphorcount + 1
        End If

        If button(c) = 2 Then
        swapver = swapver + 1
        End If
```

```
If button(c) = 3 Then
swapdiag = swapdiag + 1
End If

If button(c) = 4 Then
Bold = Bold + 1
End If

If button(c) = 5 Then
ita = ita + 1
End If

If button(c) = 6 Then
under = under + 1
End If

If button(c) = 7 Then
strike = strike + 1
End If

If button(c) = 8 Then
red = red + 1
End If

If button(c) = 9 Then
green = green + 1
End If

If button(c) = 10 Then
yellow = yellow + 1
End If

If button(c) = 11 Then
blue = blue + 1
End If

If button(c) = 12 Then
Next1 = Next1 + 1
End If

If button(c) = 13 Then
ok = ok + 1
End If

If button(c) = 14 Then
pause = pause + 1
End If

If button(c) = 15 Then
Clear1 = Clear1 + 1
End If


If button(c) = 16 Then
Reset1 = Reset1 + 1
End If

If button(c) = 21 Then
Pict1 = Pict1 + 1
End If

If button(c) = 22 Then
Pict2 = Pict2 + 1
End If

If button(c) = 23 Then
Pict3 = Pict3 + 1
End If

If button(c) = 24 Then
Pict4 = Pict4 + 1
```

```
        End If
    Next c

    If i = 11 Then
    Print #2, Text6.Text, start, swaphor, swapver, swapdiag, Bold, ita, under, strike,
red, green, yellow, blue, Next1, ok, pause, Clear1, Reset1, Pict1, Pict2, Pict3, Pict4,
cali
    start = 0
    swaphor = 0
swapver = 0
swapdiag = 0
Bold = 0
ita = 0
under = 0
strike = 0
red = 0
green = 0
yellow = 0
blue = 0
Next1 = 0
ok = 0
pause = 0
Clear1 = 0
Reset1 = 0
Pict1 = 0
Pict2 = 0
Pict3 = 0
Pict4 = 0
cali = 0
    End If

    If i = 23 Then
    Print #3, Text6.Text, start, swaphor, swapver, swapdiag, Bold, ita, under, strike,
red, green, yellow, blue, Next1, ok, pause, Clear1, Reset1, Pict1, Pict2, Pict3, Pict4,
cali
    start = 0
swaphor = 0
swapver = 0
swapdiag = 0
Bold = 0
ita = 0
under = 0
strike = 0
red = 0
green = 0
yellow = 0
blue = 0
Next1 = 0
ok = 0
pause = 0
Clear1 = 0
Reset1 = 0
Pict1 = 0
Pict2 = 0
Pict3 = 0
Pict4 = 0
cali = 0
    End If

    If i = 39 Then
    Print #4, Text6.Text, start, swaphor, swapver, swapdiag, Bold, ita, under, strike,
red, green, yellow, blue, Next1, ok, pause, Clear1, Reset1, Pict1, Pict2, Pict3, Pict4,
cali
    start = 0
swaphor = 0
swapver = 0
swapdiag = 0
Bold = 0
ita = 0
under = 0
strike = 0
```

```
red = 0
green = 0
yellow = 0
blue = 0
Next1 = 0
ok = 0
pause = 0
Clear1 = 0
Reset1 = 0
Pict1 = 0
Pict2 = 0
Pict3 = 0
Pict4 = 0
cali = 0
    End If
    Close #1
    Next i
    Close #2
    Close #3
    Close #4
End Sub
Private Sub Command3_Click()
Open "H:\terry\checkall.txt" For Append As #2
k = 1
For i = 0 To 39
    If i > 11 Then
    k = 2
    End If
    If i > 23 Then
    k = 3
    End If
filenm = "H:\terry\ " + Text5.Text + "\" + Text6.Text + "\" + Text7.Text + CStr(k) +
CStr(i) + ".csv"
Open filenm For Input As #3
n = CountLines(filenm)
c = 0
ReDim num(n) As Integer
ReDim xcor(n) As Integer
ReDim ycor(n) As Integer
ReDim time(n) As Long
ReDim button(n) As Integer

    Do While Not EOF(3)

        For j = 0 To 5 '############3
            Input #3, a(j)
        Next j

        num(c) = a(1)
        xcor(c) = a(2)
        ycor(c) = a(3)
        time(c) = a(4)
        button(c) = a(5)
        c = c + 1
    Loop
    For c = 0 To n - 1
        If c > 0 Then
            If button(c) = 13 Then
                time30 = time(c)
            End If
        End If
    Next c
    For c = 0 To n - 1
    If c > 0 Then
    If time(c) - time(c - 1) > 120 And button(c) < 30 And time(c) <= time30 Then
    Print #2, num(c), time(c), (time(c) - time(c - 1)), button(c), i, Text5.Text,
Text6.Text, Text7.Text
    End If
    End If
    Next c
    Close #3
```

```
    Next i
    Close #2

End Sub
Private Sub Command4_Click()
Open "G:\terry\new\distandcudist" + Text6.Text + ".txt" For Output As #4
Open "G:\terry\new\timebetwclicks" + Text6.Text + ".txt" For Output As #5
Open "G:\terry\new\mousedistrtest" + Text6.Text + ".txt" For Output As #6
Open "G:\terry\new\trialdurs" + Text6.Text + ".txt" For Output As #7
Open "G:\terry\new\cormcoord" + Text6.Text + ".txt" For Output As #8
Open "G:\terry\new\dispertr" + Text6.Text + ".txt" For Output As #9
Open "G:\terry\new\buttoncoords" + Text6.Text + ".txt" For Output As #10
k = 1
For i = 0 To 39
    If i > 11 Then
    k = 2
    End If
    If i > 23 Then
    k = 3
    End If
filenm = "H:\terry\dataforblanchard\" + Text5.Text + "\" + Text6.Text + "\" + Text7.Text
+ CStr(k) + CStr(i) + ".csv"
Open filenm For Input As #1

        For j = 0 To 5 '############3
            Input #1, a(j)
        Next j
correctionarray(i, 1) = a(2) '###########3
correctionarray(i, 2) = a(3) '##########3
Print #8, i, correctionarray(i, 1), correctionarray(i, 2)
Close #1
Next i
Close #8
i = 0
    maxxcor = correctionarray(i, 1)
    maxycor = correctionarray(i, 2)
    minycor = correctionarray(i, 2)
    minxcor = correctionarray(i, 1)
    For i = 0 To 39
            If correctionarray(i, 1) > maxxcor Then
                maxxcor = correctionarray(i, 1)
            End If
            If correctionarray(i, 2) > maxycor Then
                maxycor = correctionarray(i, 2)
            End If
            If correctionarray(i, 1) < minxcor Then
                minxcor = correctionarray(i, 1)
            End If
            If correctionarray(i, 2) < minycor Then
                minycor = correctionarray(i, 2)
            End If

    Next i
    shiftx = ((maxxcor - minxcor) / 2) + (minxcor - 520)
    shifty = ((maxycor - minycor) / 2) + (minycor - 370)
    Text1.Text = maxxcor
    Text2.Text = maxycor
    Text3.Text = shiftx
    Text4.Text = shifty
k = 1
For i = 0 To 39
    If i > 11 Then
    k = 2
    End If
    If i > 23 Then
    k = 3
    End If
filenm = "H:\terry\dataforblanchard\" + Text5.Text + "\" + Text6.Text + "\" + Text7.Text
+ CStr(k) + CStr(i) + ".csv"
Open filenm For Input As #1
```

```
n = CountLines(filenm)
c = 0
ReDim num(n) As Integer
ReDim xcor(n) As Integer
ReDim ycor(n) As Integer
ReDim time(n) As Long
ReDim button(n) As Integer

    Do While Not EOF(1)

        For j = 0 To 5 '############3
            Input #1, a(j)
        Next j

        num(c) = a(1)
        xcor(c) = a(2)
        ycor(c) = a(3)
        time(c) = a(4)
        button(c) = a(5)
        c = c + 1

    Loop
'adjust the values for coordinates using max and min
'summation of times in between button clicks
'summation of distances covered in between button clicks
'total number of button clicks
'number of repetitions for each button
'mouse dwell in different designated areas
cudis = 0
    For c = 0 To n - 1
        If button(c) = 30 Or button(c) = 14 Then
        Exit For
        End If
        xcor(c) = xcor(c) - shiftx
        ycor(c) = ycor(c) - shifty
        If num(c) > 0 Then
            If c > 0 Then
        dis = Sqr(((xcor(c) - xcor(c - 1)) ^ 2) + ((ycor(c) - ycor(c - 1)) ^ 2))
        cudis = cudis + dis
        Print #4, num(c), xcor(c), ycor(c), dis, cudis, button(c)

        End If
        If button(c) > 0 Then
            Print #10, num(c), xcor(c), ycor(c), time(c), button(c)
        End If
        End If
       Next c
    totaldur = 0
    tprev = time(0)
    nexttr = 0
    For c = 1 To n - 1
    If button(c) = 30 Or button(c) = 14 Then
    Exit For
    End If

    If button(c) > 0 Then
    tinterval = time(c) - tprev
   totaldur = totaldur + tinterval

    Print #5, num(c), xcor(c), ycor(c), tinterval, button(c)
        If num(c) > nexttr Then
        Print #7, num(c), totaldur
        nexttr = num(c)
        End If
    tprev = time(c)
    End If

    Next c
'------------------------------------------------------------
```

APPENDIX D

SUMMARY OF RAW DATA

The slope, intercept, correlation for the fitted power curves for individual subjects is shown in Table D1, where **a** represents the rate of learning (slope), whereas **b** represents the parameter (intercept) for the power curve equation.

Table D.1 Slope, Intercept, Correlation For The Fitted Power Curves For Individual Subjects

Compatibility	Tool Arrangment	Subjects	slope(a)	Intercept (logb)	correlation	b
1	1	1	-0.02	-0.18	-0.53	0.66
1	1	2	0.09	-0.22	0.74	0.60
1	1	3	-0.01	-0.10	-0.28	0.79
1	1	4	0.03	-0.09	0.68	0.82
1	1	5	-0.05	-0.05	-0.74	0.88
1	1	6	0.04	-0.18	0.70	0.67
1	1	7	-0.06	-0.11	-0.80	0.77
1	1	8	-0.01	-0.07	-0.43	0.84
1	2	9	0.03	-0.15	0.58	0.71
1	2	10	0.03	-0.22	0.73	0.60
1	2	11	-0.01	-0.15	-0.31	0.70
1	2	12	0.00	-0.18	0.18	0.66
1	2	13	0.06	-0.16	0.48	0.69
1	2	14	0.02	-0.20	0.57	0.63
1	2	15	0.05	-0.13	0.41	0.75
1	2	16	0.06	-0.23	0.78	0.59
2	1	17	-0.04	-0.10	-0.22	0.79
2	1	18	0.13	-0.29	0.96	0.52
2	1	19	0.08	-0.26	0.83	0.55
2	1	20	0.07	-0.21	0.55	0.62
2	1	21	0.07	-0.14	0.71	0.72
2	1	22	0.01	-0.09	0.09	0.81
2	1	23	0.08	-0.15	0.86	0.70
2	1	24	0.04	-0.19	0.58	0.64
2	2	25	0.15	-0.30	0.93	0.50
2	2	26	0.05	-0.20	0.91	0.63
2	2	27	0.15	-0.19	0.94	0.65
2	2	28	0.01	-0.07	0.36	0.86
2	2	29	0.01	-0.16	0.08	0.68
2	2	30	0.03	-0.19	0.62	0.64
2	2	31	0.19	-0.29	0.92	0.52
2	2	32	0.08	-0.21	0.81	0.62

TableD.2 Click Efficiency (E) For Task With Exploratory And Post Learning Means For Different Groups

Group	Subjects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Exploratory mean	Exploratory S.d.	Post mean	Post S.d.
Compatible from top	1	0.56	0.63	0.69	0.62	0.67	0.64	0.75	0.55	0.64	0.60	0.69	0.64	0.60	0.63	0.50	0.67	**0.63**	*0.05*	**0.61**	*0.06*
	2	0.64	0.69	0.55	0.71	0.67	0.69	0.58	0.60	0.61	0.83	0.73	0.78	0.83	0.75	0.92	0.79	**0.65**	*0.06*	**0.81**	*0.07*
	3	0.77	0.73	0.85	0.64	0.86	0.80	0.86	0.80	0.69	0.82	0.60	0.77	0.78	0.85	0.82	0.75	**0.77**	*0.09*	**0.79**	*0.04*
	4	0.58	0.71	0.91	0.91	0.92	0.93	0.56	0.92	0.92	0.92	0.80	0.92	1.00	0.75	0.94	0.86	**0.80**	*0.15*	**0.89**	*0.09*
	5	0.80	0.82	0.86	0.86	0.85	0.91	0.78	0.91	0.75	0.86	0.78	0.64	0.80	0.75	0.73	1.00	**0.84**	*0.03*	**0.79**	*0.13*
	6	0.54	0.50	0.67	0.79	0.70	0.75	0.69	0.80	0.75	0.75	0.67	0.61	0.78	0.73	0.82	0.77	**0.64**	*0.12*	**0.74**	*0.08*
	7	0.85	0.67	0.86	0.76	0.67	0.71	0.61	0.80	0.67	0.82	0.73	0.50	0.69	0.67	0.56	0.75	**0.76**	*0.09*	**0.63**	*0.10*
	8	0.77	0.85	0.86	0.88	0.92	0.70	0.75	0.92	0.79	0.79	0.91	0.88	0.69	0.75	0.90	0.92	**0.85**	*0.06*	**0.83**	*0.10*
Compatible from bottom	9	0.56	0.70	0.73	0.64	0.75	0.86	0.92	0.92	0.85	0.90	0.64	0.48	0.64	0.48	0.88	0.67	**0.68**	*0.08*	**0.63**	*0.16*
	10	0.44	0.60	0.55	0.53	0.58	0.64	0.64	0.56	0.69	0.73	0.74	0.64	0.71	0.75	0.80	0.86	**0.54**	*0.06*	**0.75**	*0.08*
	11	0.52	0.42	0.57	0.64	0.70	0.50	0.69	0.52	0.63	0.60	0.65	0.70	0.75	0.63	0.75	0.67	**0.57**	*0.11*	**0.70**	*0.05*
	12	0.80	0.56	0.71	0.67	0.65	0.56	0.82	0.63	0.53	0.75	0.50	0.82	0.92	0.92	0.73	0.85	**0.68**	*0.09*	**0.85**	*0.08*
	13	0.28	0.86	0.77	0.71	0.92	1.00	0.45	0.73	0.92	0.80	0.92	1.00	0.90	0.69	0.94	0.80	**0.71**	*0.25*	**0.87**	*0.12*
	14	0.44	0.45	0.83	0.69	1.23	0.75	0.75	0.92	0.86	0.92	0.92	0.79	0.78	0.79	0.47	0.59	**0.73**	*0.33*	**0.68**	*0.14*
	15	0.67	0.73	0.75	0.54	0.71	0.94	1.00	0.80	0.85	0.79	0.77	0.93	0.82	0.75	0.90	0.92	**0.68**	*0.08*	**0.86**	*0.08*
	16	0.43	0.50	0.55	0.89	0.93	0.35	0.60	0.80	0.56	0.80	0.85	0.70	0.63	0.63	0.79	0.80	**0.66**	*0.23*	**0.71**	*0.08*
Incompatible from top	17	0.58	0.48	0.50	0.63	0.57	0.50	0.62	0.60	0.79	0.69	0.69	0.77	0.75	0.75	0.70	0.80	**0.55**	*0.06*	**0.75**	*0.04*
	18	0.61	0.59	0.67	0.67	0.67	0.63	0.69	0.63	0.71	0.82	0.73	0.64	0.64	0.83	0.69	0.75	**0.64**	*0.04*	**0.71**	*0.08*
	19	0.63	0.58	0.80	0.47	0.71	0.89	0.92	0.92	0.85	0.92	0.91	0.93	0.75	0.90	0.90	0.92	**0.64**	*0.13*	**0.88**	*0.07*
	20	0.82	0.82	0.92	0.92	0.86	0.92	0.88	0.69	0.92	0.91	0.89	0.88	0.91	0.92	1.00	0.92	**0.87**	*0.05*	**0.92**	*0.05*
	21	0.67	0.50	0.73	0.69	0.63	0.75	0.80	0.75	0.69	0.75	0.56	0.77	0.54	0.73	0.70	0.57	**0.64**	*0.09*	**0.66**	*0.10*
	22	0.37	0.75	0.59	0.67	0.73	0.67	0.75	0.61	0.60	0.67	0.67	0.73	0.82	0.56	0.67	0.71	**0.62**	*0.16*	**0.70**	*0.09*
	23	0.65	0.46	0.63	0.60	0.61	0.41	0.75	0.91	0.73	0.57	0.88	0.90	0.91	0.75	0.92	0.86	**0.59**	*0.07*	**0.87**	*0.07*
	24	0.89	0.53	0.67	0.63	0.65	0.63	0.64	0.71	0.69	0.86	0.78	0.64	0.80	0.71	0.79	0.85	**0.67**	*0.13*	**0.76**	*0.08*
Incompatible from bottom	25	0.58	0.86	0.59	0.77	0.79	0.74	0.64	0.69	0.80	0.75	0.71	0.73	0.90	0.60	0.94	0.75	**0.72**	*0.12*	**0.78**	*0.14*
	26	0.61	0.60	0.63	0.64	0.65	0.54	0.56	0.67	0.69	0.67	0.64	0.53	0.77	0.67	0.67	0.75	**0.63**	*0.02*	**0.68**	*0.09*
	27	0.52	0.82	0.75	0.52	0.73	0.83	0.58	0.77	0.64	0.80	0.64	0.50	0.75	0.71	0.69	0.73	**0.67**	*0.14*	**0.68**	*0.10*
	28	0.56	0.75	0.57	0.67	0.67	0.79	0.58	0.60	0.69	0.71	0.70	0.70	0.45	0.71	0.80	0.69	**0.64**	*0.08*	**0.67**	*0.13*
	29	0.52	0.77	0.75	0.92	0.86	0.47	0.48	0.86	0.85	0.65	0.73	0.91	0.90	0.92	0.88	0.92	**0.76**	*0.15*	**0.91**	*0.02*
	30	0.50	0.59	0.69	0.67	0.67	0.56	0.71	0.63	0.75	0.63	0.73	0.58	0.67	0.71	0.55	0.67	**0.62**	*0.08*	**0.64**	*0.07*
	31	0.50	0.60	0.71	0.69	0.89	0.80	1.00	0.92	0.86	1.00	0.63	0.58	1.08	0.79	0.69	0.67	**0.68**	*0.14*	**0.76**	*0.19*
	32	0.53	0.44	0.69	0.50	0.71	0.60	0.80	0.71	0.65	0.75	0.53	0.77	0.64	0.73	0.58	0.63	**0.57**	*0.12*	**0.67**	*0.08*

Table D.3 Mouse Distance Per Unit Time (MT) For Task With Exploratory And Post Learning Means For Different Groups

		Trials																Exploratory		Post learning	
Group	Sub	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	mean	S.d.	mean	S.d.
Compatible from top	1	369	390	458	282	465	337	417	429	390	335	361	504	274	492	305	314	393	74.7	378	111.0
	2	480	411	432	312	381	622	670	477	307	624	285	364	524	237	607	481	403	62.1	443	145.0
	3	365	228	291	354	331	259	286	329	494	417	370	408	297	283	295	342	314	55.6	325	51.6
	4	285	250	335	448	408	288	391	359	342	268	312	263	438	246	212	307	345	82.8	293	88.2
	5	160	235	283	173	273	287	240	211	246	385	216	401	625	489	499	254	225	56.2	454	137
	6	412	359	338	367	289	338	279	313	289	353	381	299	343	383	384	490	353	44.8	380	70.8
	7	254	280	249	190	291	316	360	276	355	441	435	366	365	384	344	524	253	39.5	397	72.8
	8	146	129	199	214	233	199	264	236	299	280	306	214	251	252	310	307	184	44.5	267	41.2
Compatible from bottom	9	288	266	275	337	352	367	299	335	377	363	303	252	338	242	269	292	304	38.4	279	38.1
	10	510	483	550	529	483	465	459	528	509	423	570	422	480	459	512	480	511	29.1	471	33.2
	11	298	421	361	397	365	400	396	431	432	411	427	326	354	358	432	551	368	46.5	404	90.8
	12	373	393	313	424	349	382	439	384	360	346	416	399	379	346	323	344	370	42.1	358	30.6
	13	432	442	326	291	303	345	244	388	377	308	442	401	513	357	500	436	359	72.5	442	65.9
	14	343	281	217	224	264	270	213	333	272	339	350	318	398	338	294	321	266	50.9	334	39.1
	15	360	349	327	337	341	363	346	320	431	334	286	345	385	409	372	487	343	12.3	400	54.2
	16	460	373	396	442	274	251	217	274	228	421	272	354	245	371	465	410	389	73.0	369	81.5
Incompatible from top	17	421	437	454	439	417	456	367	464	464	393	480	413	408	419	449	282	434	15.0	394	64.5
	18	410	287	388	383	386	393	365	347	359	441	412	316	290	373	346	287	371	48.1	322	37.0
	19	319	317	227	214	270	66	250	415	258	336	494	405	247	252	459	474	270	49.1	367	111.0
	20	235	219	186	247	305	251	214	210	253	230	243	182	253	268	208	226	238	43.8	227	34.4
	21	184	217	294	290	293	301	289	314	313	368	315	348	277	352	299	375	256	51.7	330	40.5
	22	409	381	410	415	446	495	358	411	438	411	459	497	486	409	367	518	412	23.1	455	64.1
	23	339	310	428	299	371	332	325	365	394	285	338	236	282	357	317	418	350	51.9	322	69.8
	24	265	244	298	301	374	381	338	429	289	319	377	364	389	374	354	295	296	49.4	355	36.0
Incompatible from bottom	25	251	264	332	360	344	309	363	360	397	392	224	243	312	320	299	393	310	49.4	313	53.7
	26	349	261	230	584	317	396	602	396	614	299	246	597	470	554	407	443	348	140.0	494	79.1
	27	265	310	318	273	258	417	248	213	334	375	390	375	131	322	269	446	285	27.2	309	119.0
	28	346	353	525	261	309	384	168	260	241	423	337	284	348	308	285	265	359	99.6	298	32.0
	29	195	230	202	226	263	299	171	280	221	248	200	212	366	234	221	213	223	27.1	249	65.7
	30	373	264	375	328	401	347	205	296	266	332	459	384	409	324	283	116	348	53.8	514	369.0
	31	254	192	243	211	170	237	203	215	219	230	248	235	248	245	317	379	214	34.9	285	61.6
	32	709	382	507	417	679	439	563	472	603	573	715	555	514	589	618	670	539	149.0	589	59.5

Table D.4 Eye Movement Data For Compatible From Top Group (V =total visits; tv = average processing time per visit)

Sub	trials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	exploratory		post learning
1	time(seconds)	28.0	35.2	17.3	16.4	18.9	24.6	34.7	17.6	24.7	17.5	29.4	26.8	16.4	23.5	39.3	27.3	115.9		133.2
	object	27	16	12	23	12	13	11	18	13	11	16	12	12	11	15	9	90.0		59.0
	tool	10	9	9	15	11	9	10	12	7	9	9	6	10	8	10	11	54.0		45.0
	goal	14	12	11	19	17	16	14	18	16	14	9	10	11	15	14	15	73.0		65.0
	total(V)	51	37	32	57	40	38	35	48	36	34	34	28	33	34	39	35	**217.0**		**169.0**
	tv (seconds)	0.5	1.0	0.5	0.3	0.5	0.6	1.0	0.4	0.7	0.5	0.9	1.0	0.5	0.7	1.0	0.8	**0.5(0.2)**		**0.7(0.2)**
	sqrt(V)	7.1	6.1	5.7	7.5	6.3	6.2	5.9	6.9	6.0	5.8	5.8	5.3	5.7	5.8	6.2	5.9	**14.7**		**13.0**
	inv(tv)	1.8	1.1	1.9	3.5	2.1	1.5	1.0	2.7	1.5	1.9	1.2	1.0	2.0	1.4	1.0	1.3	**2.1**		**1.4**
2	time(sec)	22.9	20.0	27.0	25.4	25.2	17.0	20.6	20.1	23.2	17.9	31.1	22.3	16.3	27.8	15.5	17.3	120.4		99.3
	object	16	24	14	10	10	19	12	10	13	14	21	11	15	25	25	14	74.0		90.0
	tool	6	15	11	7	8	12	11	7	10	8	17	13	9	12	22	9	47.0		65.0
	goal	19	24	16	12	15	17	24	13	16	14	21	22	11	18	29	20	86.0		100.0
	total(V)	41	63	41	29	33	48	47	30	39	36	59	46	35	55	76	43	**207.0**		**255.0**
	tv	0.6	0.3	0.7	0.9	0.8	0.4	0.4	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.2	0.4	**0.6(0.2)**		**0.4(0.1)**
	sqrt(V)	6.4	7.9	6.4	5.4	5.7	6.9	6.9	5.5	6.2	6.0	7.7	6.8	5.9	7.4	8.7	6.6	**14.4**		**16.0**
	inv(tv)	1.8	3.1	1.5	1.1	1.3	2.8	2.3	1.5	1.7	2.0	1.9	2.1	2.1	2.0	4.9	2.5	**1.8**		**2.7**
3	time(sec)	44.5	20.5	23.0	22.0	21.5	15.8	34.0	15.4	18.5	18.8	15.0	22.2	22.9	24.8	22.9	16.0	131.5		108.7
	object	35	18	21	15	15	12	19	9	14	12	15	15	18	18	16	8	104.0		75.0
	tool	18	6	9	7	7	5	8	7	6	7	4	8	9	7	8	5	47.0		37.0
	goal	25	17	19	15	16	13	31	11	12	15	11	22	20	20	17	14	92.0		93.0
	total(V)	78	41	49	37	38	30	58	27	32	34	30	45	47	45	41	27	**243.0**		**205.0**
	tv	1	0.9	0.8	1	0.9	0.9	0.9	0.9	1	0.9	1	0.7	0.8	0.9	0.91	0.84	**0.9 (0.1)**		**0.8 (0.08)**
	sqrt(V)	8.8	6.4	7.0	6.1	6.2	5.5	7.6	5.2	5.7	5.8	5.5	6.7	6.9	6.7	6.4	5.2	**15.6**		**14.3**
	inv(tv)	1.0	1.1	1.2	1.0	1.1	1.1	1.1	1.2	1.0	1.2	1.0	1.4	1.3	1.1	1.1	1.2	**1.1**		**1.2**
4	time(sec)	44.5	20.5	23.0	22.0	21.5	15.8	34.0	15.4	18.5	18.8	15.0	22.2	22.9	24.8	22.9	16.0	131.5		108.7
	object	35	18	21	15	15	12	19	9	14	12	15	15	18	18	16	8	104.0		75.0
	tool	18	6	9	7	7	5	8	7	6	7	4	8	9	7	8	5	47.0		37.0
	goal	25	17	19	15	16	13	31	11	12	15	11	22	20	20	17	14	92.0		93.0
	total(V)	78	41	49	37	38	30	58	27	32	34	30	45	47	45	41	27	**243.0**		**205.0**
	tv	1	0.9	0.8	1	0.9	0.9	0.9	0.9	1	0.9	1	0.7	0.8	0.9	0.91	0.84	**0.9 (0.1)**		**0.8 (0.08)**
	sqrt(V)	8.8	6.4	7.0	6.1	6.2	5.5	7.6	5.2	5.7	5.8	5.5	6.7	6.9	6.7	6.4	5.2	**15.6**		**14.3**
	inv(tv)	1.0	1.1	1.2	1.0	1.1	1.1	1.1	1.2	1.0	1.2	1.0	1.4	1.3	1.1	1.1	1.2	**1.1**		**1.2**

Table D.5 Eye Movement Data For Compatible From Bottom Group (V =total visits; tv = average processing time per visit)

Sub	trials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	exploratory	post learning
5	time(seconds)	23.7	28.8	30.1	20.5	23.7	24.5	23.2	22.8	21.5	20.3	33.1	35.4	16.3	29.0	26.0	24.4	126.8	131.2
	object	20	19	25	18	16	20	16	18	15	18	31	28	12	16	18	20	98	94
	tool	9	8	9	8	9	10	8	9	9	9	13	8	7	9	8	10	43	42
	goal	15	20	23	16	15	13	12	13	13	12	22	13	12	13	18	12	89	68
	total(V)	44	47	57	42	40	43	36	40	37	39	66	49	31	38	44	42	230	204
	tv (seconds)	0.5	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.7	0.5	0.8	0.6	0.6	0.5 (0.1)	0.6 (0.1)
	sqrt(V)	6.6	6.9	7.5	6.5	6.3	6.6	6.0	6.3	6.1	6.2	8.1	7.0	5.6	6.2	6.6	6.5	15.2	14.3
	inv(tv)	1.9	1.6	1.9	2.1	1.7	1.8	1.6	1.8	1.7	1.9	2.0	1.4	1.9	1.3	1.7	1.7	1.8	1.6
6	time(seconds)	25.3	22.0	15.6	13.0	15.0	15.5	17.9	13.6	15.0	24.2	17.2	18.4	14.8	19.1	16.0	18.0	91.0	86.3
	object	15	16	16	12	14	15	18	12	10	24	15	14	13	17	12	12	73	68
	tool	10	11	10	6	8	7	9	8	9	15	10	10	8	13	8	11	45	50
	goal	16	19	13	10	11	11	11	11	12	22	15	12	11	12	13	14	69	62
	total(V)	41	46	39	28	33	33	38	31	31	61	40	36	32	42	33	37	187	180
	tv (seconds)	0.6	0.5	0.4	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5 (0.1)	0.5 (0.07)
	sqrt(V)	6.4	6.8	6.2	5.3	5.7	5.7	6.2	5.6	5.6	7.8	6.3	6.0	5.7	6.5	5.7	6.1	13.7	13.4
	inv(tv)	1.6	2.1	2.5	2.2	2.2	2.1	2.1	2.3	2.1	2.5	2.3	2.0	2.2	2.2	2.1	2.1	2.1	2.1
7	time(seconds)	42.3	18.8	19.7	17.4	22.6	33.7	48.7	21.2	15.4	21.0	22.4	12.1	14.3	14.4	13.2	13.6	120.9	67.7
	object	29	14	15	14	18	22	29	14	16	18	12	12	12	10	12	9	90	55
	tool	15	9	8	9	10	7	8	7	6	8	8	9	8	7	9	7	51	40
	goal	23	10	9	12	14	20	24	13	12	14	13	7	10	9	10	5	68	41
	total(V)	67	33	32	35	42	49	61	34	34	40	33	28	30	26	31	21	209	136
	tv (seconds)	0.6	0.6	0.6	0.5	0.5	0.7	0.8	0.6	0.5	0.5	0.7	0.4	0.5	0.6	0.4	0.6	0.6 (0.1)	0.5 (0.1)
	sqrt(V)	8.2	5.7	5.7	5.9	6.5	7.0	7.8	5.8	5.8	6.3	5.7	5.3	5.5	5.1	5.6	4.6	14.5	11.7
	inv(tv)	1.6	1.8	1.6	2.0	1.9	1.5	1.3	1.6	2.2	1.9	1.5	2.3	2.1	1.8	2.3	1.5	1.8	2.0
8	time(seconds)	36.0	35.7	32.5	45.1	34.1	32.7	36.8	32.2	21.3	26.4	24.9	23.0	25.4	23.5	30.3	35.6	183.3	137.8
	object	28	27	31	39	19	25	34	28	16	19	24	19	18	22	19	24	144	102
	tool	15	16	19	23	13	13	19	15	10	11	13	10	13	14	13	12	86	62
	goal	18	23	26	30	22	20	29	19	17	19	19	14	16	19	18	24	119	91
	total(V)	61	66	76	92	54	58	82	62	43	49	56	43	47	55	50	60	349	255
	tv (seconds)	0.6	0.5	0.4	0.5	0.6	0.6	0.4	0.5	0.5	0.5	0.4	0.5	0.5	0.4	0.6	0.6	0.5 (0.1)	0.5 (0.1)
	sqrt(V)	7.8	8.1	8.7	9.6	7.3	7.6	9.1	7.9	6.6	7.0	7.5	6.6	6.9	7.4	7.1	7.7	18.7	16.0
	inv(tv)	1.7	1.9	2.3	2.0	1.6	1.8	2.2	1.9	2.0	1.9	2.2	1.9	1.9	2.3	1.7	1.7	1.9	1.9

Table D.6 Eye Movement Data For Incompatible From Top Group (V =total visits; tv = average processing time per visit)

Sub	trials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Expl	Post
9	time(sec)	**27.9**	16.0	15.1	15.4	18.7	16.5	28.1	19.8	12.8	17.3	14.3	13.0	12.3	13.1	16.0	23.4	93.1	77.8
	object	17	10	11	13	16	12	17	12	8	13	13	10	8	8	15	7	67	48
	tool	16	7	9	9	9	8	15	9	8	9	7	7	6	6	7	8	50	34
	goal	15	13	11	13	12	15	20	13	10	11	10	5	5	9	12	12	64	43
	total(V)	48	30	31	35	37	35	52	34	26	33	30	22	19	23	34	27	181	125
	tv (sec)	0.6	0.5	0.5	0.4	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.9	0.5 (0.1)	0.6 (0.1)
	sqrt(V)	6.9	5.5	5.6	5.9	6.1	5.9	7.2	5.8	5.1	5.7	5.5	4.7	4.4	4.8	5.8	5.2	13.5	11.2
	inv(tv)	1.7	1.9	2.1	2.3	2.0	2.1	1.8	1.7	2.0	1.9	2.1	1.7	1.6	1.8	2.1	1.2	1.9	1.6
10	time(sec)	22.1	27.6	44.4	32.3	48.7	125	37.3	19.5	32.0	24.1	19.7	26.6	27.6	26.3	15.4	35.1	175.0	131.0
	object	18	20	19	14	17	13	16	15	16	24	22	17	13	18	18	16	88	82
	tool	12	8	7	8	19	10	7	9	11	9	9	9	13	8	9	7	54	46
	goal	2	14	9	9	35	19	15	16	15	21	12	17	14	12	8	12	69	63
	total(V)	32	42	35	31	71	42	38	40	42	54	43	43	40	38	35	35	211	191
	tv (sec)	0.7	0.7	1.3	1.0	0.7	3.0	1.0	0.5	0.8	0.4	0.5	0.6	0.7	0.7	0.4	1.0	0.8 (0.3)	0.6 (0.3)
	sqrt(V)	5.7	6.5	5.9	5.6	8.4	6.5	6.2	6.3	6.5	7.3	6.6	6.6	6.3	6.2	5.9	5.9	14.5	13.8
	inv(tv)	1.4	1.5	0.8	1.0	1.5	0.3	1.0	2.1	1.3	2.2	2.2	1.6	1.5	1.4	2.3	1.0	1.2	1.6
11	time(sec)	16.1	22.0	21.9	23.7	20.7	18.8	18.9	21.7	20.5	11.4	17.7	22.4	22.0	13.3	19.3	31.7	104.4	108.7
	object	11	15	17	16	16	15	17	16	15	12	14	17	18	10	13	16	75	74
	tool	9	8	9	14	12	10	8	9	9	6	7	7	8	5	8	7	52	35
	goal	9	11	16	12	11	11	14	15	14	11	13	20	17	7	10	14	59	68
	total(V)	29	34	42	42	39	36	39	40	38	29	34	44	43	22	31	37	186	177
	tv (sec)	0.6	0.6	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.6	0.6	0.9	0.6 (.07)	0.6 0.08)
	sqrt(V)	5.4	5.8	6.5	6.5	6.2	6.0	6.2	6.3	6.2	5.4	5.8	6.6	6.6	4.7	5.6	6.1	13.6	13.3
	inv(tv)	1.8	1.5	1.9	1.8	1.9	1.9	2.1	1.8	1.9	2.5	1.9	2.0	2.0	1.6	1.6	1.2	1.8	1.7
12	time(sec)	27.1	17.0	22.1	26.8	28.7	23.1	18.3	20.6	21.9	14.1	22.2	18.4	24.6	21.1	26.4	32.5	121.7	122.9
	object	17	12	11	11	13	13	13	13	13	13	13	11	8	13	20	13	64	65
	tool	11	11	9	7	9	9	9	9	9	9	9	8	6	9	15	8	47	46
	goal	11	10	5	11	10	10	10	10	10	10	10	8	7	12	14	8	47	49
	total(V)	39	33	25	29	32	32	32	32	32	32	32	27	21	34	49	29	158	160
	tv (sec)	0.7	0.5	0.9	0.9	0.9	0.7	0.6	0.6	0.7	0.4	0.7	0.7	1.2	0.6	0.5	1.1	0.7 0.07)	0.7 0.09)
	sqrt(V)	6.2	5.7	5.0	5.4	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.2	4.6	5.8	7.0	5.4	12.6	12.6
	inv(tv)	1.4	1.9	1.1	1.1	1.1	1.4	1.8	1.6	1.5	2.3	1.4	1.5	0.9	1.6	1.9	0.9	1.3	1.3

Table D.7 Eye Movement Data For Incompatible From Bottom Group (V =total visits; tv = average processing time per visit)

Sub	trials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	expl	post
13	time(sec)	30	26.7	26.6	16.4	38.4	17.3	18.6	25.7	19.5	31.8	25.4	14.5	17.0	15.2	16.3	17.2	137.9	80.2
	object	19	21	21	15	22	14	14	18	13	16	16	12	11	9	13	10	98.0	55.0
	tool	12	13	11	7	10	7	7	6	8	12	11	8	9	7	7	8	53.0	39.0
	total(V)	44	45.0	45.0	35.0	44.0	21.0	21.0	24.0	21.0	28.0	27.0	29.0	30.0	24.0	27.0	27.0	213.0	137.0
	tv (sec)	1.2	1.1	1.1	0.8	1.7	2.5	2.7	4.3	2.4	2.7	2.3	0.9	0.9	1.0	1.2	1.0	1.1	1.0
	sqrt(V)	6.6	6.7	6.7	5.9	6.6	4.6	4.6	4.9	4.6	5.3	5.2	5.4	5.5	4.9	5.2	5.2	14.6	11.7
	inv(tv)	0.8	0.9	0.9	1.2	0.6	0.4	0.4	0.2	0.4	0.4	0.4	1.2	1.1	1.0	0.9	1.0	0.9	1.0
14	time(sec)	53	25.9	32.8	31.1	22.1	23.9	41.3	28.4	25.3	28.4	30.9	21.7	15.8	25.4	18.1	31.2	164.9	112.5
	object	11	18	13	14	12	20	22	17	19	11	13	12	8	12	16	13	68	61
	tool	6	13	7	9	8	9	6	6	6	5	6	8	4	7	8	9	43	36
	total(V)	25	42	29	30	32	29	28	23	25	16	19	30	19	25	31	33	111	97
	tv (sec)	2.1	0.6	1.1	1.5	0.6	0.8	1.47	1.2	1.2	1.7	1.6	0.7	0.8	1.02	0.6	0.9	0.9	0.8
	sqrt(V)	5	6.4	5.3	5.4	5.6	5.3	5.2	4.7	5	4	4.3	5.4	4.3	5	5.5	5.74	10.5	9.8
	inv(tv)	0.4	1.6	0.8	0.9	1.4	1.2	0.6	0.8	0.9	0.5	0.6	1.3	1.2	1	1.7	1.1	1.1	1.2
15	time(sec)	18.5	32.1	22.6	26.4	38.9	27.2	29.4	25.4	27	31.7	20.5	22.2	23.5	18.7	15.4	14.2	138.1	94.1
	object	21	14	21	18	22	19	11	12	11	11	15	18	19	11	17	14	96	79
	tool	15	8	9	7	13	10	8	7	6	8	8	10	9	6	9	9	52	43
	goal	13	11	16	12	12	15	16	12	10	10	8	15	14	19	9	11	64	68
	total(V)	49	33	46	37	47	44	35	31	27	29	31	43	42	36	35	34	212	190
	tv (sec)	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1
	sqrt(V)	1.5	0.5	1.1	0.71	0.6	0.9	0.8	0.7	0.6	0.5	0.7	1.1	0.9	1.3	1.1	1.4	0.9	1.2
	inv(tv)	7	5.74	6.7	6.1	6.8	6.6	5.9	5.5	5.2	5.3	5.5	6.5	6.5	6	5.9	5.8	14.5	13.8

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration

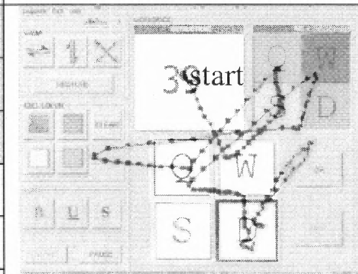
1		2	3	4		5		6
Eye Move And Final Position		**Activity between successive mouse events(clicks)** Mental/ motor Actions Involved	Mouse events	Time (ms)		Total Action Time (a+b)		Scan path generated/duration
From	To			a. Approx Eye Movement time to reqd. position (ms)	b. Approximate Dwell time at position (ms)			
Start	G_Q	Goal acceptance and formation and creation of subjective model of situation; selection of object(O_D) for subsequent subtask execution. (includes simultaneous perceptual actions, with explorative thinking. Comparison of object and goal in relation to the program of performance.)		150	180	330	Simultaneous perceptual actions	 Figure 1
G_Q	O_q			150	220	370	Simultaneous perceptual actions	
O_q	T_{CB}			180	150	330	Simultaneous perceptual actions	
T_{CB}	G_S			180	220	400	Thinking action based on visual information	
G_S	G_D			150	190	340	Thinking action based on visual information	
G_D	O_q			210	220	430	Thinking action based on visual information	
O_q	O_W			150	330	480	Thinking action based on visual information	
O_W	O_D			150	190	340	Thinking action based on visual information	
O_D	G_D	Decision on program of performance and motor action based on decision.		210	190	400	Thinking action based on visual information	

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

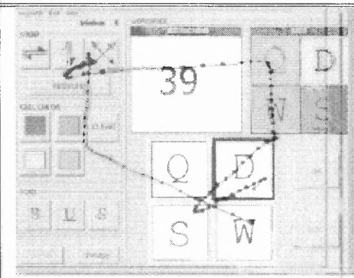
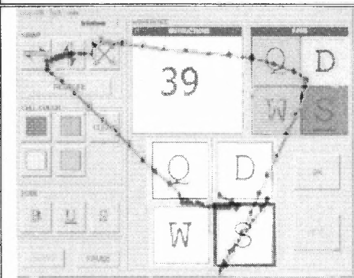
G_D	O_D	Perceptual action with motor action and thinking based on program of performance	Click object element D with mouse	210	630	840	Decision making action at sensory perceptual level. With simultaneous Motor action	
O_D	T_{PV}	Motor action of eye and mouse along with selection from choice of tools		210	220	430	Simultaneous perceptual action with motor action	
T_{PV}	G_D	Eye move to goal area with mouse stationary at tool. Use of peripheral vision for mouse control while focus on goal area.	Click vertical positionin g tool.	150	420	570	Simultaneous perceptual action Decision making action during visual assessment. Motor action;	Figure 2
G_D	O_D	Perceptual action on object for developing and		180	220	400	Decision making action at sensory perceptual level.	
O_D	O_Q			90	220	310	Thinking action based on visual information	
O_Q	O_D			150	250	400	Thinking action based on visual information	
O_D	O_S			150	250	400	Thinking action based on visual information	
O_S	G_W	Decision involving program of performance and tool choice for the next course of action		150	180	330	Thinking action based on visual information	Figure 3
G_W	T_{PH}			150	330	480	Thinking action based on visual information	
T_{PH}	O_Q			150	180	330	Thinking action based on visual information	

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

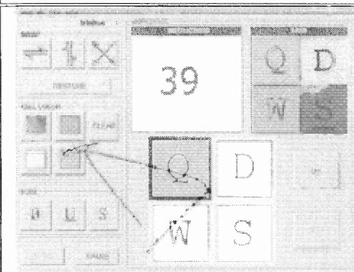
O_Q	O_S	Initiate motor action and start of next subtask based on accepted program of performance based on intermediate stage	Click of Object S	60	220	280	Decision making action at sensory perceptual level. With simultaneous Motor action.	
O_S	T_{PH}	Tool selection and thinking action for assessing the outcome of action		330	870	1200	Thinking action, decision-making action at sensory perceptual level with simultaneous motor action.	
T_{PH}	G_S	Perceptual action for desired outcome	Click Horizontal Position tool	180	220	400	Simultaneous perceptual action with motor action	
G_S	O_Q	Comparing desired outcome to actual using simultaneous perceptual action	Click to select object Q.	150	180	330	Decision making action at sensory perceptual level.	 Figure 4
O_Q	G_S	Visit goal for next stage of performance		150	220	370	Thinking action based on visual information	
G_S	T_{CB}	Tool selection based on accepted program of performance		180	240	420	Decision making action at sensory perceptual level.	

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

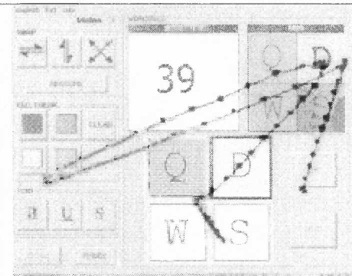
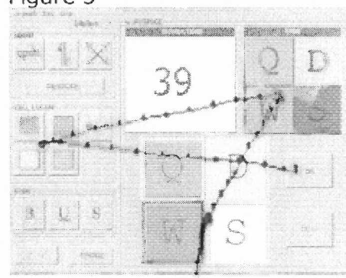
T_{CB}	G_Q	Comparing desired outcome to actual using simultaneous perceptual action	Click blue coloring tool.	180	220	400	Decision making action at sensory perceptual level. With simultaneous Motor action.	 Figure 5
G_Q	O_D	Perceptual action for identification of next set of actions to be performed for completion	click object D	150	330	480	Simultaneous perceptual action with motor action	
O_D	T_{CY}	Tool selection and initiate motor action		180	330	510	Simultaneous perceptual action with motor action	 Figure 6
T_{CY}	O_D	Perceptual action for getting feedback on action	Click yellow color tool	210	210	420	Simultaneous perceptual action	
O_D	O_W	Moving to the next object towards completion of task and subsequent motor action for selection	Click object W	150	390	540	Simultaneous perceptual action with motor action Decision making action at sensory perceptual level.	
O_W	T_{CG}	Tool selection based on program of performance	Click green color tool	150	720	870	Simultaneous perceptual action with motor action Decision making action	

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

T_{CG}	O_S	Less cognitive overload on feedback requiring less time and includes the corresponding action of moving on with the next stage of task	Click object s	150	330	480	Simultaneous perceptual action with motor action	
O_S	G_S	Compares goal		150	330	480	Thinking action based on visual information	
G_S	T_{CR}	Tool selection based on desired program of performance		180	780	960	Decision making action at sensory perceptual level. Motor action Memory action	
T_{CR}	G_w	No feedback required from object directly goes to the goal for formulating next set of program	Click red color tool	180	190	370	Sensory perceptual action with motor action	
G_w	G_S			60	190	250	Thinking action	
G_S	T_{FU}, T_{FS}	Misinterpretation of feature and improper tool selection	Click underline tool	180	900	1080	Thinking action Decision making Motor action	
T_{FU}, T_{FS}	O_S	Corrective action based on feed back and proper tool selection	Remove underline	180	220	400	Sensory perceptual action with motor action	
O_S	G_S		Click strike through	120	220	340	Thinking action	
G_S	G_Q			120	250	370	Thinking action	

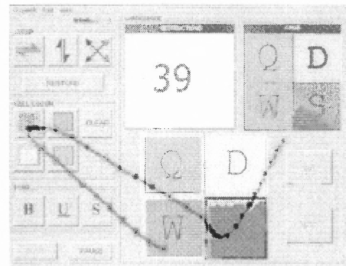


Figure 7

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

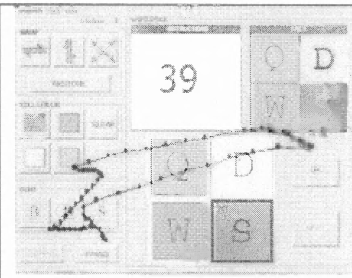
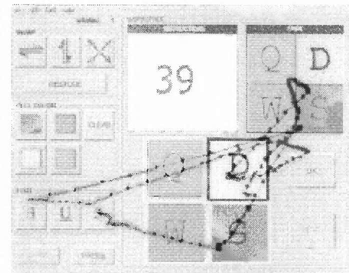
G_Q	G_D			180	240	420	Thinking action	
G_D	O_D	Object selection based on program of performance	Click object D	240	250	490	Decision making Simultaneous perceptual and Motor action	Figure 8
O_D	T_{FB}	Tool perception and decision on selection		150	250	400	Decision making with simultaneous perceptual action and feedback	
T_{FB}	G_W	Tool action with focus on feedback	Click bold tool	120	240	360	Simultaneous perceptual action with motor action	
G_W	O_D	Assessing status of objects for finalizing		150	930	1080	Memory action Thinking action	
O_D	OK	Decision making for end of task. Subjective assessment of completion of task.	Finish	120	250	370	Decision making action with simultaneous perceptual action Motor action	Figure 9

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

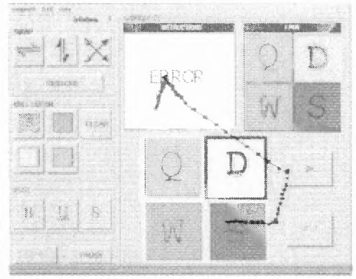
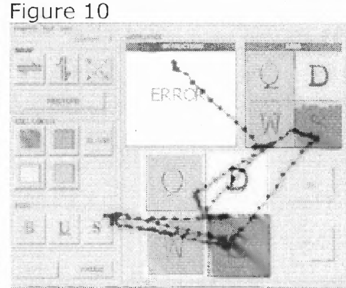
OK	G_S	Corresponding perceptual action on feedback and goal for assessing incorrectness and incompleteness in task.		150	220	370	simultaneous perceptual actions	 Figure 10
G_S	Feed			150	210	360	simultaneous perceptual actions	 Figure 11
Feedback	G_W			120	540	660	thinking action with simultaneous perceptual actions	
G_W	O_Q	Revisit objects for detection of error perceptual actions with memory action		150	600	750	Memory action , thinking action with simultaneous perceptual actions	
O_Q	G_S	Visit goal for finalizing program of performance based on error detection Decision on program of performance		180	220	400	Simultaneous perceptual action	

Table D.8 Tabular Presentation Of Activity Elements Associated With Eye Movement Registration (continued)

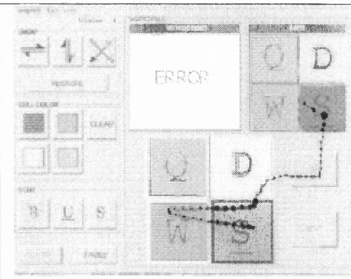
G_S	O_S	Motor action for executing program of performance	Select object s	150	220	370	Decision making with motor action	 Figure 12
O_S	T_{FU}	Tool selection for correction of error.	Remove strike	150	220	370	Simultaneous perceptual action with motor action	
T_{FU}	O_D	Final comparison of goal and acceptance of completion of task	Click underline	150	280	430	Simultaneous perceptual action with motor action	
O_D	OK		Finish	120	390	510	Memory action Thinking action and Decision making at sensory perceptual level	
OK	Finish						Simultaneous perceptual action with motor action	

Table D.9 Algorithm Of Human Performance

Algorithm	Description	Actions obtained from action classification table	Time (ms)
O_1^{α}	Look at goal area and initial state of object area.	Simultaneous perceptual actions (3 actions)	1030
$O_2^{\alpha th}$	Find out differences between goal area and object area.	Thinking actions based on visual information (4 actions)	1650
$O_3^{\alpha th}$	Find out differences between goal area and object area and simultaneously perform O_4^{ε}	Thinking actions based on visual information (2 actions)	740
O_4^{ε}	Move cursor closely to object area.	Simple motor action.	
l_1	Decide to click object (element O_D) and simultaneously perform O_5^{ε}	Decision making action based on information from memory.	840
O_5^{ε}	Simultaneously with l_1 , click object element O_D	Simple motor action.	
O_6^{α}	Look at tool area and simultaneously perform O_7^{ε}	Simultaneous perceptual action	430
O_7^{ε}	Simultaneously with O_6^{α} move cursor closer to tool area.	Simple motor action	
l_2	Decide to click object (element O_D) and simultaneously perform O_8^{ε}	Simultaneous perceptual action Decision making action during visual assessment.	570
O_8^{ε}	Simultaneously with l_2 move cursor close to specific icon and click icon	Precise motor action	
$O_9^{\alpha th}$	Evaluate how object area matched to goal area.	Thinking action based on visual information	400
$O_{10}^{\alpha th}$	Evaluate intermittent state of object area.	Thinking actions based on visual information (4 actions)	1740
O_{11}^{α}	Look at goal area and then look at tool area	Simultaneous perceptual actions (2 actions)	
l_3	Decide to click object (element O_s) and simultaneously perform O_{12}^{ε}	Decision making action at sensory perceptual level.	280
O_{12}^{ε}	Simultaneously with l_3 , click object element O_s, by using mouse.	Simple motor action.	
O_{13}^{α}	Look at tool area and simultaneously perform O_{14}^{ε}	Simultaneous perceptual action with partly overlapping motor action (see below)	1200

Table D.9 Algorithm Of Human Performance (continued)

O_{14}^{ε}	Simultaneously with O_{13}^{α} move cursor close to specific icon (horizontal position tool)	Precise motor action.	
O_{15}^{α}	Look at object area to evaluate change of position of objects (O_S and O_W –horizontal shift) and perform O_{16}^{ε}	Simultaneous perceptual action with motor action(see below)	400
O_{16}^{ε}	Click tool to activate action simultaneously performed with O_{15}^{α}	Simple motor action.	
O_{17}^{α}	Continue looking at object area	Simultaneous perceptual action	
l_4	Decide to click object (element O_Q) and simultaneously perform O_{18}^{ε}	Decision making action at sensory perceptual level.	330
O_{18}^{ε}	Click object element O_Q	Simple motor action.	
O_{19}^{α}	Look at goal area to evaluate color of elements.	Simultaneous perceptual action	370
l_5	Decide to click blue icon tool.	Decision making action at sensory perceptual level.	420
O_{20}^{α}	Look at tool area and simultaneously perform O_{21}^{ε}	Simultaneous perceptual action with motor action	400
O_{21}^{ε}	Move cursor to tool area	Precise motor action	
l_6	Decide to click object (element O_Q) and simultaneously perform O_{22}^{ε}	Simultaneous perceptual action with motor action Decision making action at sensory perceptual level.	330
O_{22}^{ε}	Click object element O_Q	Simple motor action	
O_{23}^{α}	Look at tool area and simultaneously perform O_{24}^{ε}	Simultaneous perceptual action with motor action	420
O_{24}^{ε}	Move cursor to blue color tool.	Precise motor action	
O_{25}^{α}	Look at object area and simultaneously perform O_{26}^{ε}	Simultaneous perceptual action with motor action	400
O_{26}^{ε}	Click blue color tool performed simultaneously with O_{27}^{α}	Simple motor action	
O_{27}^{α}	Continue looking at object area	Simultaneous perceptual action	
l_7	Decide to click object O_D and simultaneously perform O_{28}^{ε}	Decision making action at sensory perceptual level.	480
O_{28}^{ε}	Move cursor to O_D and click O_D	Precise motor action	
O_{29}^{α}	Look at tool area and simultaneously perform O_{30}^{ε}	Simultaneous perceptual action with motor action	510
O_{30}^{ε}	Move cursor to yellow color tool.	Precise motor action	
O_{31}^{α}	Look at object area and simultaneously perform O_{32}^{ε}	Simultaneous perceptual action with motor action	420

Table D.9 Algorithm Of Human Performance (continued)

O_{32}^{ε}	Click yellow color tool	Simple motor action	
O_{33}^{α}	Continue looking at object area	Sensory perceptual action with motor action	540
O_{34}^{α}	Look at tool area (green color tool) and simultaneously perform O_{35}^{ε}	Sensory perceptual action with motor action	870
O_{35}^{ε}	Move to green color tool and click green tool	Precise motor action	
O_{36}^{α}	Look at object area and simultaneously perform O_{37}^{ε}	Sensory perceptual action with motor action	
O_{37}^{ε}	Click green color tool	Simple motor action	
O_{38}^{α}	Continue looking at object area and simultaneously perform O_{39}^{ε}	Simultaneous perceptual action with motor action	480
O_{39}^{ε}	Move cursor to object area	Simple motor Action	
O_{40}^{α}	Look at goal area and perceive color of goal element S simultaneously perform O_{43}^{ε}	Simultaneous perceptual action with motor action	480
O_{41}^{ε}	Click object element O_S and simultaneously perform O_{42}^{α}	Simple motor Action	
O_{42}^{α}	Look at tool area (red color tool) and simultaneously perform O_{45}^{ε}	Simultaneous perceptual actions	960
O_{43}^{ε}	Move cursor to red color tool	Precise motor Action	
O_{44}^{α}	Look at object area (O_S) and simultaneously perform O_{45}^{ε}	Simultaneous perceptual action with motor action	370
O_{45}^{ε}	Click red color tool	Simple motor action.	
O_{46}^{α}	Look at goal area	Simultaneous perceptual action	250
O_{47}^{α}	Look at tool area and simultaneously perform O_{48}^{ε}	Simultaneous perceptual action with motor action	1080
O_{48}^{ε}	Move cursor to tool area	Simple motor action.	
$O_{49}^{\alpha th}$	Evaluate function of tools.	Thinking action under visual information	400
l_9	Decide to use strike tool	Decision making action	340
O_{50}^{α}	Look at goal area and simultaneously perform O_{51}^{ε}	Simultaneous perceptual action with motor action	370
O_{51}^{ε}	Move cursor to object area	Simple motor action.	
O_{52}^{α}	Continue looking at goal area	Simultaneous perceptual action	420
l_{10}	Decide to change object O_D	Decision making action	490
O_{53}^{α}	Look at object O_D and simultaneously perform O_{55}^{ε}	Simultaneous perceptual action with motor action	
O_{54}^{ε}	Click object element O_D	Simple motor action.	

Table D.9 Algorithm Of Human Performance (continued)

O_{55}^{α}	Look at tool area and simultaneously perform O_{57}^{ε}	Simultaneous perceptual action with motor action	400
O_{56}^{ε}	Move to tool element bold	Precise motor action.	
O_{57}^{α}	Look at goal area and simultaneously perform O_{59}^{ε}	Simultaneous perceptual action with motor action	360
O_{58}^{ε}	Click bold tool	Simple motor action.	
$O_{59}^{\alpha th}$	Look at goal and object area for finalizing status of objects as per the requirements of the goal.	Thinking action	1080
l_{10}	Look at object area and simultaneously perform O_{61}^{α} and O_{62}^{ε}	Decision making for finalization of task completion	370
O_{60}^{α}	Look at object area and simultaneously perform O_{62}^{ε}	Simultaneous perceptual action with motor action	
O_{61}^{ε}	Move cursor to finish button.	Simple motor action.	
O_{62}^{α}	Continue looking at object area and simultaneously perform O_{64}^{ε}	Simultaneous perceptual action with motor action	370
O_{63}^{ε}	Click finish for feedback	Simple motor action.	
O_{64}^{α}	Look at feedback area (area showing error).	Simultaneous perceptual action	360
$O_{65}^{\alpha th}$	Evaluate error information	Thinking action	660
$O_{67}^{\alpha th}$	Look at object area to detect source of error and evaluate error.	Thinking action	750
O_{68}^{α}	Look at goal area	Simultaneous perceptual action	400
O_{69}^{α}	Look at object area and simultaneously perform O_{70}^{ε}	Simultaneous perceptual action with motor action	370
O_{70}^{ε}	Click object element O_S	Simple motor action.	
O_{71}^{α}	Continue looking at tool area and simultaneously perform O_{72}^{ε}	Simultaneous perceptual action with motor action	370
O_{72}^{ε}	Click strike to remove effect.	Simple motor action.	
O_{73}^{α}	Look at object area and simultaneously perform O_{74}^{ε}	Simultaneous perceptual action with motor action	430
O_{74}^{ε}	Click tool underline	Simple motor action.	
O_{75}^{α}	Look at object area and simultaneously perform O_{76}^{ε}	Simultaneous perceptual action with motor action	510
O_{76}^{ε}	Click OK to complete trial.	Simple motor action.	

APPENDIX E

SAS LISTINGS OF DATA ANALYSIS

E.1 Introduction

All the SAS listings based on the code (see Figure D.1) is given in the following sections. For the reader those values used in the analysis and interpretation of the results and are reported in the main text are given in bold face formatting.

```
data repeated;
input subject compatibility toolarrangment phase1 phase2;
cards;

1       1       1       0.631410256     0.605606061
2       1       1       0.65063368      0.813980464
3       1       1       0.768531469     0.793338361
4       1       1       0.804812834     0.892997199
5       1       1       0.835724276     0.785238095
6       1       1       0.637298933     0.741926962
7       1       1       0.75970696      0.634294872
8       1       1       0.854120879     0.828076923
.....   .......  ..............................data lines.............................................. . .
;
run;

PROC GLM DATA = repeated ;
        CLASS compatibility tool arrangement;
        MODEL phase1 phase2 = compatibility tool arrangement
compatibility*tool arrangement ;
        repeated phase 2 / printe short summary;
        means compatibility tool arrangement compatibility tool
arrangement  compatibility*toolarrangement/bon;
    lsmeans compatibility toolarrangement compatibility toolarrangement
compatibility*toolarrangement /tdiff adjust=bon;

RUN ;
```

Figure E.1 SAS code sample used for analysis of repeated measures (the inset shows efficiency (E) as the dependent variable

E.2 SAS listing for click efficiency (E)

The SAS System

The GLM Procedure

Class Level Information		
Class	Levels	Values
compatibility	2	1 2
tool arrangement	2	1 2

Number of observations	32

The GLM Procedure

Repeated Measures Analysis of Variance

Tests of Hypotheses for Between Subjects Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
compatibility	1	0.005	0.005	0.52	0.47
tool arrangement	1	0.015	0.015	1.54	0.22
compatibility*tool arrangement	1	0.011	0.011	1.19	0.28
Error	28	0.273	0.009		

The GLM Procedure

Repeated Measures Analysis of Variance

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
phase	1	0.107	0.107	27.46	<. 0001
phase*compatibility	1	0.031	0.031	8.14	0.008
phase*tool arrangement	1	0.000	0.000	0.02	0.89
phase*compatibility*tool arrangement	1	0.006	0.006	1.66	0.20
Error(phase)	28	0.109	0.003		

The GLM Procedure

Bonferroni (Dunn) t Tests for Exploratory Learning

NOTE: This test controls the Type I experiment wise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	0.004

Critical Value of t	2.0481
Minimum Significant Difference	0.05

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	Compatibility
A	0.704	16	1
B	0.642	16	2

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	0.008
Critical Value of t	2.048
Minimum Significant Difference	0.06

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	Compatibility
A	0.76	16	2
A			
A	0.74	16	1

The GLM Procedure

Bonferroni (Dunn) t Tests for Exploratory Learning

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	0.004
Critical Value of t	2.04
Minimum Significant Difference	0.05

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	tool arrangement
A	0.68	16	1
A			
A	0.65	16	2

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	0.008
Critical Value of t	2.04
Minimum Significant Difference	0.06

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	tool arrangement
A	0.77	16	1
A			
A	0.73	16	2

The GLM Procedure

Level of compatibility	Level of tool arrangement	N	Exploratory Learning		Post Learning	
			Mean	Std Dev	Mean	Std Dev
1	1	8	0.74	0.09	0.76	0.09
1	2	8	0.66	0.05	0.72	0.08
2	1	8	0.63	0.05	0.78	0.09
2	2	8	0.65	0.06	0.75	0.09

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	Exploratory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	0.70	2.55	0.01
2	0.64		

compatibility	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	0.74	-0.80	0.42
2	0.76		

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

tool arrangement	Exploratory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	0.68	1.17	0.2505
2	0.65		

tool arrangement	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	0.77	0.98	0.3365
2	0.73		

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	Tool arrangement	Exploratory Learning LSMEAN	LSMEAN Number
1	1	0.74	1
1	2	0.66	2
2	1	0.63	3
2	2	0.65	4

Least Squares Means for Effect compatibility*tool arrangement t for H0: LSMean(i)=LSMean(j) / Pr > |t| Dependent Variable: Exploratory Learning				
i/j	1	2	3	4
1		2.19 0.21	3.17 0.02	2.63 0.0812
2	-2.19 0.2197		0.97 1.0000	0.44 1.0000
3	-3.1 0.0219	-0.97 1.0000		-0.53 1.0000
4	-2.63 0.0812	-0.44 1.0000	0.53 1.0000	

compatibility	tool arrangement	Post Learning LSMEAN	LSMEAN Number
1	1	0.76	1
1	2	0.72	2
2	1	0.78	3
2	2	0.75	4

Least Squares Means for Effect compatibility*tool arrangement t for H0: LSMean (i)=LSMean (j) / Pr > |t| Dependent Variable: Click Efficiency (E) at Post Learning				
i/j	1	2	3	4
1		0.83 1.0000	-0.42 1.0000	0.12 1.0000
2	-0.83 1.00		-1.25 1.0000	-0.71 1.0000
3	0.42 1.0000	1.25 1.0000		0.54 1.0000
4	-0.12 1.0000	0.71 1.0000	-0.54 1.0000	

E.3 SAS listing for mouse distance traversed per unit time (MT)

The SAS System

The GLM Procedure

Class Level Information		
Class	Levels	Values
compatibility	2	1 2
tool arrangement	2	1 2

Number of observations	32

The SAS System

The GLM Procedure

Repeated Measures Analysis of Variance

Tests of Hypotheses for Between Subjects Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
compatibility	1	1353.4361	1353.4361	0.12	0.7369
tool arrangement	1	10961.4389	10961.4389	0.93	0.3424
compatibility*tool arrangement	1	1244.2374	1244.2374	0.11	0.7473
Error	28	329090.2488	11753.2232		

The SAS System

The GLM Procedure

Repeated Measures Analysis of Variance

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
phase	1	21947.52937	21947.52937	9.08	0.0054
phase*compatibility	1	23.79777	23.79777	0.01	0.9217
phase*tool arrangement	1	28.75269	28.75269	0.01	0.9139
phase*compatibility*tool arrangement	1	5594.93531	5594.93531	2.32	0.1393
Error(phase)	28	67664.73367	2416.59763		

The SAS System

The GLM Procedure

Bonferroni (Dunn) t Tests for Exploratory Learning

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	6843.688
Critical Value of t	2.04841
Minimum Significant Difference	59.912

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	compatibility
A	336.21	16	1
A			
A	328.24	16	2

The SAS System

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	7326.133
Critical Value of t	2.04841
Minimum Significant Difference	61.988

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	compatibility

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	compatibility
A	374.47	16	1
A			
A	364.05	16	2

The SAS System

The GLM Procedure

Bonferroni (Dunn) t Tests for Exploratory Learning

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	6843.688
Critical Value of t	2.04841
Minimum Significant Difference	59.912

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	tool arrangement
A	345.98	16	2
A			
A	318.47	16	1

The SAS System

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	7326.133
Critical Value of t	2.04841
Minimum Significant Difference	61.988

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	tool arrangement
A	381.68	16	2
A			
A	356.84	16	1

The SAS System

The GLM Procedure

Level of compatibility	Level of tool arrangement	N	Exploratory Learning		Post Learning	
			Mean	Std Dev	Mean	Std Dev
1	1	8	308.696500	80.113200	366.993184	67.279067
1	2	8	363.729523	71.735251	381.945480	60.911340
2	1	8	328.237068	73.992321	346.694953	65.849736
2	2	8	328.233566	101.665221	381.410025	129.350994

The SAS System

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	Exploratory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	336.213012	0.27	0.7870
2	328.235317		

compatibility	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	374.469332	0.34	0.7332
2	364.052489		

The SAS System

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

tool arrangement	Exploratory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	318.466784	-0.94	0.3549
2	345.981545		

tool arrangement	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	356.844068	-0.82	0.4188
2	381.677753		

The SAS System

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	tool arrangement	Exploratory Learning LSMEAN	LSMEAN Number
1	1	308.696500	1
1	2	363.729523	2
2	1	328.237068	3
2	2	328.233566	4

Least Squares Means for Effect compatibility*tool arrangement
t for H0: LSMean(i)=LSMean(j) / Pr > |t|

Dependent Variable: Exploratory Learning

i/j	1	2	3	4
1		-1.33048 1.0000	-0.47241 1.0000	-0.47233 1.0000
2	1.33048 1.0000		0.858066 1.0000	0.858151 1.0000
3	0.472413 1.0000	-0.85807 1.0000		0.000085 1.0000
4	0.472329 1.0000	-0.85815 1.0000	-0.00008 1.0000	

compatibility	tool arrangement	Post Learning LSMEAN	LSMEAN Number
1	1	366.993184	1
1	2	381.945480	2
2	1	346.694953	3
2	2	381.410025	4

Least Squares Means for Effect compatibility*tool arrangement
t for H0: LSMean(i)=LSMean(j) / Pr > |t|

Dependent Variable: Post Learning

i/j	1	2	3	4
1		-0.34938 1.0000	0.474297 1.0000	-0.33687 1.0000
2	0.349382 1.0000		0.823679 1.0000	0.012512 1.0000
3	-0.4743 1.0000	-0.82368 1.0000		-0.81117 1.0000
4	0.33687 1.0000	-0.01251 1.0000	0.811168 1.0000	

E.4 SAS listing for total eye visits (V)

The GLM Procedure

Repeated Measures Analysis of Variance

Tests of Hypotheses for Between Subjects Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
compatibility	1	6.81727813	6.81727813	11.86	0.0049
tool arrangement	1	0.89445313	0.89445313	1.56	0.2361
compatibility*tool arrangement	1	6.57937812	6.57937812	11.45	0.0054
Error	12	6.89826250	0.57485521		

The GLM Procedure

Repeated Measures Analysis of Variance

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
phase	1	0.03187813	0.03187813	0.31	0.5882
phase*compatibility	1	0.10465313	0.10465313	1.02	0.3334
phase*tool arrangement	1	0.14177812	0.14177812	1.38	0.2635
phase*compatibility*tool arrangement	1	0.07702812	0.07702812	0.75	0.4042
Error(phase)	12	1.23621250	0.10301771		

The GLM Procedure

Bonferroni (Dunn) t Tests for Exploratory Learning

NOTE: This test controls the Type I experiment wise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.306154
Critical Value of t	2.17881
Minimum Significant Difference	0.6028

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	compatibility
A	2.2538	8	1
B	1.2163	8	2

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.371719
Critical Value of t	2.17881
Minimum Significant Difference	0.6642

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	compatibility
A	2.2025	8	1
B	1.3938	8	2

The GLM Procedure

Bonferroni (Dunn) t Tests for Exploratory Learning

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.306154
Critical Value of t	2.17881
Minimum Significant Difference	0.6028

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	tool arrangement
A	1.9688	8	2
A			
A	1.5013	8	1

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.371719
Critical Value of t	2.17881
Minimum Significant Difference	0.6642

Means with the same letter are not significantly different.			
Bon Grouping	Mean	N	tool arrangement
A	1.8988	8	2
A			
A	1.6975	8	1

The GLM Procedure

Level of compatibility	Level of tool arrangement	N	Exploratory Learning		Post Learning	
			Mean	Std Dev	Mean	Std Dev
1	1	4	1.51750000	0.47947019	1.69750000	0.68752576
1	2	4	2.99000000	0.76432977	2.70750000	0.40925746
2	1	4	1.48500000	0.63121576	1.69750000	0.90370995
2	2	4	0.94750000	0.10996211	1.09000000	0.17320508

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	Exploratory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	2.25375000	3.75	0.0028
2	1.21625000		

compatibility	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	2.20250000	2.65	0.0211
2	1.39375000		

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

tool arrangement	Exploratory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	1.50125000	-1.69	0.1169
2	1.96875000		

tool arrangement	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|

tool arrangement	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	1.69750000	-0.66	0.5216
2	1.89875000		

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	tool arrangement	Exploratory Learning LSMEAN	LSMEAN Number
1	1	1.51750000	1
1	2	2.99000000	2
2	1	1.48500000	3
2	2	0.94750000	4

Least Squares Means for Effect compatibility*tool arrangement
t for H0: LSMean (i)=LSMean (j) / Pr > |t|

Dependent Variable: Exploratory Learning

i/j	1	2	3	4
1		-3.76357 0.0162	0.083067 1.0000	1.456867 1.0000
2	3.763572 0.0162		3.846639 0.0139	5.220438 0.0013
3	-0.08307 1.0000	-3.84664 0.0139		1.3738 1.0000
4	-1.45687 1.0000	-5.22044 0.0013	-1.3738 1.0000	

compatibility	tool arrangement	Post Learning LSMEAN	LSMEAN Number
1	1	1.69750000	1
1	2	2.70750000	2
2	1	1.69750000	3
2	2	1.09000000	4

Least Squares Means for Effect compatibility*tool arrangement
t for H0: LSMean (i)=LSMean (j) / Pr > |t|

Dependent Variable: Post Learning

i/j	1	2	3	4
1		-2.34277 0.2232	0 1.0000	1.40914 1.0000
2	2.342767		2.342767	3.751907

Least Squares Means for Effect compatibility*tool arrangement t for H0: LSMean (i)=LSMean (j) / Pr > |t| Dependent Variable: Post Learning

Class Level Information		
Class	**Levels**	**Values**
compatibility	2	1 2
tool arrangement	2	1 2

i/j	1	2	3	4
	0.2232		0.2232	0.0166
3	0 1.0000	-2.34277 0.2232		1.40914 1.0000
4	-1.40914 1.0000	-3.75191 0.0166	-1.40914 1.0000	

E.5 SAS listing for average processing time per visit (tv)

Number of observations	16

The SAS System

The GLM Procedure

Repeated Measures Analysis of Variance

Tests of Hypotheses for Between Subjects Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
compatibility	1	2.93439032	2.93439032	11.99	0.0047
tool arrangement	1	0.00316574	0.00316574	0.01	0.9113
Compatibility*tool arrangement	1	0.59069934	0.59069934	2.41	0.1463
Error	12	2.93723359	0.24476947		

The SAS System

The GLM Procedure

Repeated Measures Analysis of Variance

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F
phase	1	0.05477878	0.05477878	0.76	0.3990
phase*compatibility	1	0.00015412	0.00015412	0.00	0.9638
phase*tool arrangement	1	0.00103192	0.00103192	0.01	0.9064
phase*Compatibility*tool arrangement	1	0.05058692	0.05058692	0.71	0.4171

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Error(phase)	12	0.85945181	0.07162098		

The SAS System

The GLM Procedure

Bonferroni (Dunn) t Tests for Exporatory Learning

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.114402
Critical Value of t	2.17881
Minimum Significant Difference	0.3685

Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**compatibility**
A	1.7088	8	1
B	1.1075	8	2

The SAS System

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.201988
Critical Value of t	2.17881
Minimum Significant Difference	0.4896

Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**compatibility**
A	1.7959	8	1
B	1.1859	8	2

The SAS System

The GLM Procedure

Bonferroni (Dunn) t Tests for Exporatory Learning

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.114402
Critical Value of t	2.17881
Minimum Significant Difference	0.3685

Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**tool arrangement**
A	1.4238	8	2
A			
A	1.3925	8	1

The GLM Procedure

Bonferroni (Dunn) t Tests for Post Learning

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.201988
Critical Value of t	2.17881
Minimum Significant Difference	0.4896

Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**tool arrangement**
A	1.4951	8	2
A			
A	1.4866	8	1

The SAS System

The GLM Procedure

Level of compatibility	Level of tool arrangement	N	Exporatory Learning		Post Learning	
			Mean	Std Dev	Mean	Std Dev
1	1	4	1.51750000	0.47947019	1.69551480	0.69042224
1	2	4	1.90000000	0.14988885	1.89626092	0.21496604
2	1	4	1.26750000	0.43949782	1.27769731	0.50532779
2	2	4	0.94750000	0.10996211	1.09402178	0.17234854

The SAS System

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	Exporatory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	1.70875000	3.56	0.0040
2	1.10750000		

compatibility	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	1.79588786	2.71	0.0188
2	1.18585954		

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

tool arrangement	Exporatory Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	1.39250000	-0.18	0.8565
2	1.42375000		

tool arrangement	Post Learning LSMEAN	H0:LSMean1=LSMean2	
		t Value	Pr > |t|
1	1.48660605	-0.04	0.9703
2	1.49514135		

The GLM Procedure

Least Squares Means

Adjustment for Multiple Comparisons: Bonferroni

compatibility	tool arrangement	Exporatory Learning LSMEAN	LSMEAN Number
1	1	1.51750000	1
1	2	1.90000000	2
2	1	1.26750000	3
2	2	0.94750000	4

Least Squares Means for Effect Compatibility*tool arrangement t for H0: LSMean(i)=LSMean(j) / Pr > |t| Dependent Variable: Exporatory Learning				
i/j	1	2	3	4
1		-1.5993 0.8144	1.045293 1.0000	2.383268 0.2073
2	1.599298 0.8144		2.644591 0.1283	3.982566 0.0109
3	-1.04529 1.0000	-2.64459 0.1283		1.337975 1.0000
4	-2.38327 0.2073	-3.98257 0.0109	-1.33798 1.0000	

compatibility	tool arrangement	Post Learning LSMEAN	LSMEAN Number
1	1	1.69551480	1
1	2	1.89626092	2
2	1	1.27769731	3
2	2	1.09402178	4

Least Squares Means for Effect Compatibility*tool arrangement t for H0: LSMean(i)=LSMean(j) / Pr > |t| Dependent Variable: Post Learning				
i/j	1	2	3	4
1		-0.63168 1.0000	1.314736 1.0000	1.892703 0.4966
2	0.631683 1.0000		1.946418 0.4524	2.524385 0.1602
3	-1.31474 1.0000	-1.94642 0.4524		0.577967 1.0000
4	-1.8927 0.4966	-2.52439 0.1602	-0.57797 1.0000	

APPENDIX F

SYSTEMIC-STRUCTURAL THEORY OF ACTIVITY BASICS

E.1 Background

AT derives its roots from the Marxist theory of "dialectical materialism". Founders of AT were Russian scientists Rubenshtein, Vygotsky and Leontev. Basic research from an AT perspective in the HCI- related field includes contributions in Information Systems (Helen Hasan, 2000), Computer Mediated Communications (Kaari Kuutti, 1998), Human Computer Interaction (Kaptelinin, 1994), Computer Science, (Boedker, 1991), AT is defined as a goal directed, artifact mediated set of actions for accomplishing a certain objective. Recent research has defined Activity (Deyatel'nost') as a coherent system of internal mental processes, external behavior and motivation that are combined and directed to achieve a conscious goal (G. Bedny, D. Meister, 1997). Basically AT promotes a systemic-structural approach in study of human performance.

Activity is described as a multidimensional system (G.Bedny, 2000.). An activity can be studied from a cognitive perspective when it is a process, morphological analysis perspective when actions and operations are a major concern and functional analysis when the basic unit is function blocks. One important feature of system-structural analysis is that the hierarchical description of activity embraces certain principles, which involve both conscious and unconscious processing of information, and the study of cognitive and motor actions that are self-regulated for the objective of accomplishing a desired goal. In the process it involves several feed forward and feedback loops influenced by the nature of the task situation.

A fundamental theoretical concept in AT is internalization. According to Vygotsky (1964), internalization is the transformation into an internal mental plane of external performance in social interactions. According to Bedny (1981), object practical actions emerge as a basis for the formation of the internal mental actions. External actions are not transformed into the internal plane but are an important precondition for the formation of internal cognitive actions based on mechanisms of self-regulation. Mental actions begin internally with external support. At the first step internal plane of activity evolves with the support of external activity. Only later mental plane of activity becomes independent.

From the discussion above it can be concluded that cognitive psychology, which is the primary tool for studying human-computer-interactions possesses one serious drawback- by studying cognition separately from behavior. Cognition and behavior must be studied in unity. Activity Theory can mitigate the limitation of Cognitive Psychology, which separates cognition and behavior while addressing the various issues in interface design. Activity approach definitely leads to more general and precise concepts of subjects, tools, object, goal, task, mental and behavioral actions, and self- regulations, which are important in the study of HCI.

E.2 Overview Of Activity Theory

The concept of activity (deyatelnost) plays a key role in Russian psychology and ergonomics, which is a coherent system of internal mental processes and external mental behavior and motivation that are combined and directed to achieve a conscious goal.

Goal is the second important feature. The goal manifests itself as the image of the desired result in the future. Awareness of the goal is of prime importance as the kind of goal influences and determines the other activity aspects. The other different parameters of work activity consist of the actual output, the strategies used, the individual style, the prescribed method for the particular work, and several internal and external attributes of human performance, which permit the organization of human activity to achieve the desired goal. However, the goal reached as a result of the actual output, more specifically identified as outcome, may vary from the desired one and interestingly is subjected to changes during the performance of work. This is addressed by the concept of self-regulation. Self-regulation postulates that an operator, during task performance, can compare the desired goal with the actual outcome and adjust behavior after evaluating discrepancy.

A fundamental component of AT is the task. The tasks described in AT can be divided in two basic types of components- the cognitive component and the motor component, which can then be divided into further subdivisions based on the type of task involved. In visual search tasks we can identify these two as the cognitive processes during visual search as the cognitive component and the eye movements as the motor component.

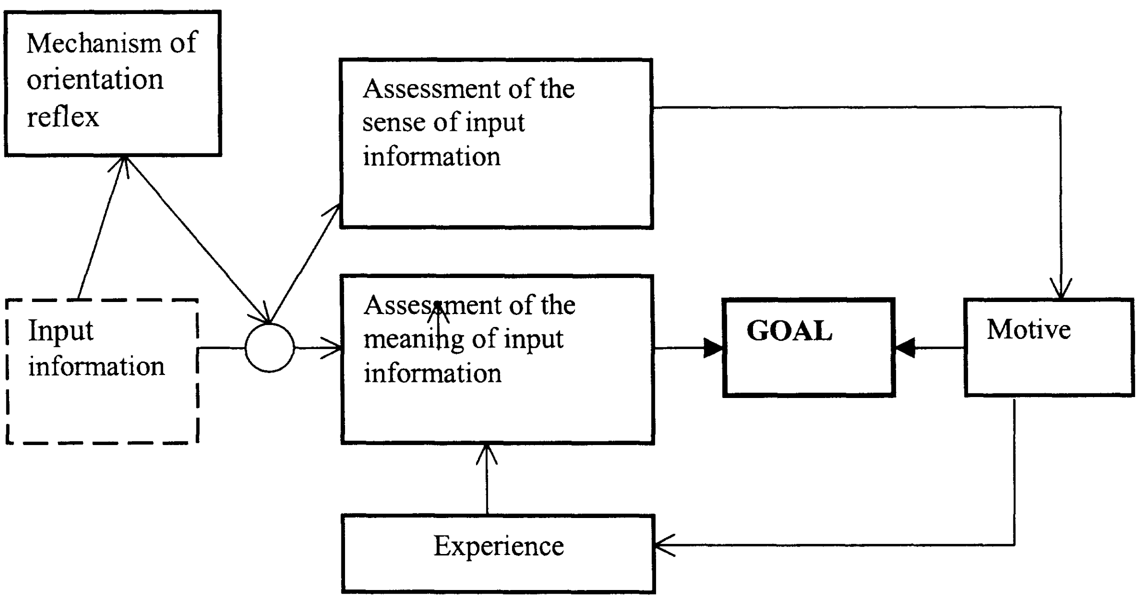


Figure F.1 Model of goal formation

These processes from the AT point of view are interrelated. This unique feature of AT empowers it to identify a relationship between the cognitive and the motor component of Visual Search and thereby develop a more general model. This will not only involve the task situation (situation awareness) but also address the phenomena as an interrelation and interaction of the various components. Figure F.1 represents the process of goal formation and the associated elements during human activity. In this study AT is used as a theoretical lens to understand a very simple interaction of users with one of the most widely used software. In the following sections the different tools offered by Activity Theory is discussed briefly.

F.3 Tools Of Systemic-Structural Theory Of Activity

Systemic structural analysis of human activity can be performed in two directions as indicated in Figure F.2 with various tools of analysis.

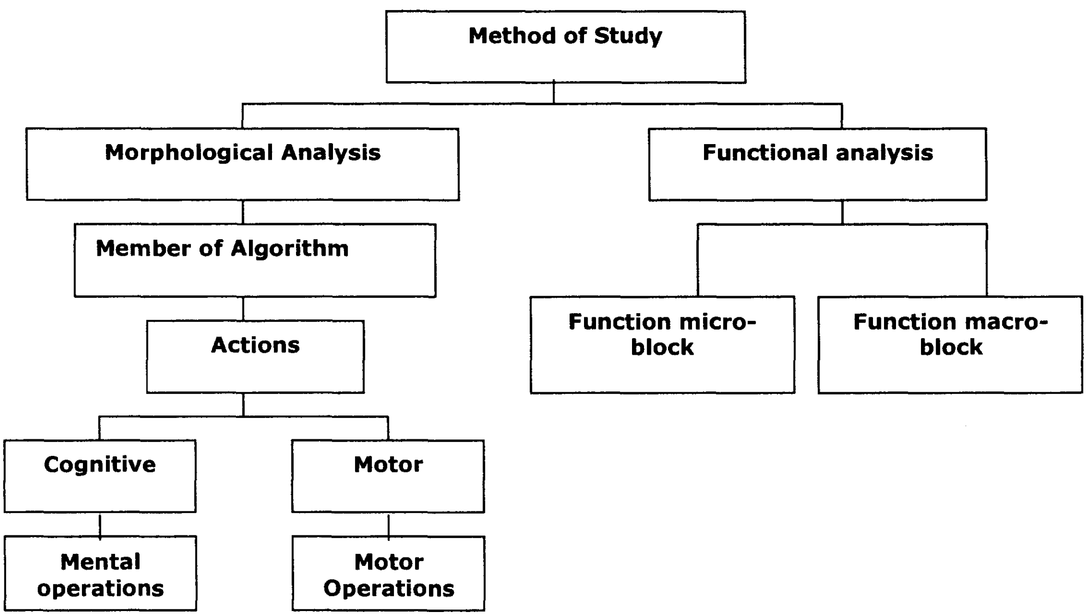


Figure F.2 Major units of analysis in systemic-structural theory of activity

The model of human performance can be derived on the basis of morphological analysis, which requires the identification of the members of algorithm (one complete set of purposeful action or actions) according to a set of actions and operations. These actions and operations are associated to the eye and mouse movements in the experimental study. The experimental hypotheses were required in order to test whether the relationship between the performance and the eye and mouse movements exist or not and whether they are affected by usability.

F.4 Mental actions and operations

According to the systemic-structural theory of activity, major units of analysis during morphological study are cognitive and behavioral actions. Actions have a temporal dimension and begin when an individual accepts the goal of the action and they are completed when the individual achieves conscience goal of the actions and evaluates the result of actions according to an established goal. Therefore, during systemic-structural analysis very often it is useful or even required to determine the durations of mental and motor actions. Each action should also be classified according to the criteria, which were developed in system structural theory of activity (Bedny, Seglin & Meister, 2000).

For example, there are sensory actions, simultaneous perceptual actions, mnemonic thinking actions etc. They are classified on the basis of the dominating cognitive activity at that particular time. Thinking actions related to transformative actions can be classified in a more detailed way as decision making actions, categorization actions etc. (for a complete review see Bedny et al., 2000).

It should be noted that according to the systemic-structural theory of activity there are simultaneous perceptual actions (SPA) and successive perceptual actions (SuPA). SPA s are involved in the identification of clearly distinguished stimuli and are involved in the immediate recognition. SuPA s are involved in the interpretation of information from unfamiliar stimuli which require the creation of a perceptual image. They require more deliberate examination and analysis of stimuli. In this study, most of the stimuli are well defined and well rehearsed by the subject and hence simultaneous perceptual actions are more significant than successive perceptual actions.

According to activity theory the capacity of visual perception during one dwell depends on the angle of vision, and the amount of elements inside the visual field in which the dwell occurs. This visual angel is of about ten degrees can accommodate about four to six elements. Therefore the tool area consists of sub areas, which are basically the functional groups of different types of tools, which can be perceived simultaneously by the subject. Goal and object are consisting of 4 elements, which also fall in an approximate visual angle of 10 degrees (Lomov, ed., 1982). Hence, each area requires simultaneous perceptual actions. Only comparison of different areas can require successive perceptual actions. The task also requires the comparison of functional relationships between different elements of the goal and the object areas and hence includes thinking actions.

F.5 Algorithm (model) of human performance

Algorithmic analysis of task performance is a powerful method of task analysis. There are two meanings of the term method associated with the algorithmic task analysis. One meaning of method is associated with a set of structured operations, which should be performed by the user. This is classical task analysis or hierarchical task analysis as prescribed in several human computer interaction studies. Most of the studies involving the analysis of human-computer tasks require an initial task analysis to be performed so that the task may be analyzed for the optimality of performance under the restrictions of the user interface requirements. The other meaning of method may be extracted from the set of instructions, which describes to the user what should be performed to accomplish a particular task. For example, when a specialist pays attention to a method by which a user performs the task he/she has in mind users' actions and operations, which are used for accomplishing a goal of task.

There are different understandings of the word algorithm. The term algorithm is mostly associated with a mathematical set of instructions, which requires an input and provides an output based on the input. On the other hand a human algorithm is a precise description of logical sequences of human cognitive and motor actions and operations, which are used by a subject or an operator to accomplish a task's goal (Bedny Karwowski, 2003). Hence, the reader is thereby made aware of the distinction of the notions of algorithm is used in various perspectives. This study uses the latter notion to study human performance using a set of logically organized motor and mental actions. Human algorithms are basically evolving. The more the algorithm is used the more the subject will adjust the different actions and operations to improve the algorithm. The algorithm therefore consists of mental actions and operations and their logical organization is an important aspect of algorithmic task analysis. To achieve this goal this study uses eye and mouse movement analysis in unity as a basis for algorithmic analysis. The dissertation demonstrated the existence of relationships between eye and mouse movements during task performance and the influence of usability on them.

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