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TASK INTERRUPTION AND ITS EFFECTS ON MEMORY

A DISSERTATION

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BY

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This work is dedicated to my mother and to the memory of my father. They taught me the value of education and hard work and that any goal can be achieved by combining them. I am also grateful for the support of my brother Matt and sister Marcy. My wife Jackie was by far the most important person in helping me achieve this goal. Her unending patience, understanding, and sense of humor were invaluable. I would also like to thank Jim Hawthorne, Steve Lewandowsky, and Jorge Mendoza for their helpful comments and valuable insights as members of my committee. I will always be indebted to Scott Gronlund, my graduate advisor, and Frank Durso, another committee member, who spent countless hours reading drafts of my manuscripts, challenging my ideas, and encouraging me to *think* throughout my graduate training. I am sure that I do not yet fully appreciate the value of their guidance, encouragement, and friendship.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

FIGURE Page

ABSTRACT

The memorial effects of interruptions were examined by training subjects to retrieve a set of items from specific locations. Subjects in the Fixed group retrieved the same set of items in the same sequence during each training session. The Arbitrary group retrieved the same set of items in a different random sequence during each training session. During the last training session, subjects were unknowingly interrupted for three minutes with either a task-similar or task-dissimilar interruption. Upon completion of the interruption, subjects were queried regarding the location they were at before the interruption, and the item they were about to retrieve. The Fixed group was better than the Arbitrary group at remembering the item they were about to get. When asked about their location prior to the interruption, the two groups did equally well after the task-dissimilar interruption; however, the Arbitrary group did much worse after the task-similar interruption. Although the Fixed group was immune from the detrimental effect of interruption similarity found in previous research, interruption-similarity adversely affected both types of memory tasks for the Arbitrary group. Discussion focuses on the nature of the memory representation of the Fixed group that insulates them from the effects of interruptions.

Introduction

A Boeing 747 full of passengers and luggage awaits departure clearance before traveling overseas. The pilot has spent numerous hours in a high-fidelity simulator preparing for this moment. As he awaits final clearance, he spends the last few moments going through his pre-flight checklist. Nearly all take-off procedures are completed when the co-pilot questions him regarding the filing of the flight-plan. Final clearance is received and the aircraft enters the runway under full power. The aircraft leaves the ground, but is quickly slammed back to the runway. No one is injured, but this pilot's first commercial flight nearly ends in disaster because he forgot to return to his checklist after being interrupted by the co-pilot. Had he remembered, he would have noticed that the rudder was locked and remedied the situation.

Interruptions are a common occurrence in everyday life; in fact, they sometimes seem to be the rule rather than the exception. Even the simple task of retrieving electronic mail can lead to several minutes of interruptions (Cypher, 1986). Although interruptions do not typically have such drastic consequences as in the above example, they often leave us with a loss of memory regarding what we were doing before we were interrupted. On the other hand, sometimes we recover easily from an interruption and go on to finish the main task.

Interruption recovery requires that components of the interrupted (main) task are held externally or in memory until the interruption is remedied and the main task resumed. The present research examines two factors that may impact interruption recovery: the relationship between the main task and the interruption task, and the nature of the long-term memory representation. However, before reviewing recent interruption research, let us look briefly at the earliest empirical investigations of interruptions.

Historical Overview

The first research specifically aimed at examining the effects of interruptions was conducted by a student of Lewin's named Zeigarnik. The specific question posed by Zeigarnik was, "What is the relation between the retention of activities that have been interrupted before completion and the retention of completed activities?" (1927, p. 3). She gave subjects a series of 22 tasks (e.g., paper folding, counting backwards, straightening wire), presented one-at-a-time. Half of the tasks were interrupted before completion and half were completed. After the 22 tasks had been administered, Zeigarnik asked what tasks the subject had worked on during the experiment. She found that the tasks that were interrupted prior to completion were recalled better than those that were not interrupted. In addition, subjects tended to recall interrupted tasks first. Ovsiankina (1928), another student of Lewin's, examined the conditions under which interrupted tasks would be resumed. The idea was that if a quasi-need was established by interrupting a task, then that task would be more likely to be spontaneously resumed following the interruption. Ovsiankina presented subjects with 8 to 12 tasks, 6 to 8 of which were interrupted deliberately or accidentally. She found that *all* of the accidentally interrupted tasks and 74% of the deliberately interrupted tasks were resumed within 20 seconds after the interruption task was completed.

Viewing interruptions from a cognitive perspective can offer an explanation for why interrupted tasks are remembered better, and why there is a "need" to complete them. For example, the relatively long period of time (to a cognitive psychologist) that it took for Ovsiankina's subjects to resume interrupted tasks (20 s) suggests the strategic use of memory to reconstruct the retrieval environment and help recover from an interruption, rather than the automatic retrieval of this information. The long response time may indicate that interruption recovery is a type of problem-solving process (Williams & Hollan, 1981) that uses several memory cues to recursively reconstruct the pre-interruption situation. Of interest then are factors that influence the reconstruction of the pre-interruption situation, in particular, he similarity between the main task and the interruption task, and the nature of the memory representation of the main task.

The majority of studies have found what we call an interruption-similarity effect. This effect is characterized by a greater reduction in performance following a similar interruption than following a dissimilar interruption. The problem, however, is that similarity means different things to different investigators (see Medin, Goldstone, & Gentner, 1993). For example, two tasks may be similar in the materials they share, the cognitive processes they require, or both, or in yet some other way. These characteristics are discussed in the *Interruption Taxonomy* section below.

As the main task becomes more familiar, memory for the main task may be less affected by the characteristics of the interruption. Specifically, familiarity with the main task may interact with the interruption-similarity effect. This idea is discussed further in the section entitled *Familiarity and Changes to the Memory Representation.* Let us now turn to a taxonomy of interruption characteristics and how they might influence memory for the main task.

Interruption Taxonomy

We define interruptions as any interference with working memory (WM; Baddeley, 1986, 1990). This interference may be overcome by the contextual and temporal knowledge in long-term memory (LTM), reinstating the pre-interruption contents of WM. The interruption will be disruptive when LTM cannot provide the proper contextual or temporal information. This definition will be used to help explain the effects found in previous research.

To begin examining similarity between the main and interruption tasks, we first discuss similarity in terms of shared materials and then in terms of processing similarity.

Similarity due to Shared Materials. The effect of similar interruptions on mission control personnel was recently investigated by NASA. Czerwinski, Chrisman, and Rudisill (1991) examined the effect of similarity of the interruption on memory for spacecraft characteristics. Subjects monitored four spacecraft systems for aberrant values over a specific time period. Interruption similarity was manipulated by requiring subjects to review either the same four spacecraft subsystems for a previous day (similar) or a daily schedule for each crew member (dissimilar). Czerwinski, et al., found that only interruptions similar to the main task (i.e., the two shared similar materials) significantly impaired recall of the main task characteristics.

Shared materials may have an especially detrimental effect when the main task is not well-represented in LTM. Memory traces that are laid down as a result of the interruption may interfere with memory for the main task during retrieval. The traces of the most recently experienced event (e.g., the interruption) may block the retrieval of the main task (Chandler, 1991, 1993; E. F. Loftus & Loftus, 1980; E. F. Loftus, 1981). A main task that is well-represented in LTM, on the other hand, might overcome this interference by utilizing the information that a well-organized memory representation provides.

Similarity of Processing. Gillie and Broadbent (1989) examined the effects of shared processes on the ability to complete a computer-based adventure game. Subjects were given a list of items embedded in a plausible scenario and asked to retrieve items from the locations. For example, if the item was *bread*, they were to move to the *bakery* and retrieve it. The interruption was a free recall task. Gillie and Broadbent assumed that the free recall task and the main task shared similar process because both were memory-intensive. They found that completion of the main task was significantly slowed following the free recall task. From these results, Gillie and Broadbent concluded that interruptions are disruptive when the main and interruption tasks are similar in the degree of processing involved.

A similar result was found by Kreifeldt and McCarthey (1981). They examined the effects of a similar interruption on the time to restart a problem post interruption. Subjects completed problems on calculators in either Algebraic or Reverse Polish Notation. Subjects were interrupted after 12 seconds with the task of writing out multiplication tables for one minute. Kreifeldt and McCarthey found that regardless of the calculator used, the time to restart the problem was greater after the interruption than was the time to start the problem initially. Kreifeldt and McCarthey suggested that after the interruption, subjects must reorganize the problem before it can be restarted, and this takes more time than what was required to begin the problem. However, the increased time to begin the problem post-interruption may be a function of the similarity between the main and interruption tasks (both required multiplication). If the interruption had not been similar to the main task, post-interruption reorganization may not have been necessary.

Both Gillie and Broadbent (1989) and Kreifeldt and McCarthey (1981) found that similar interruptions lead to slower task completion times than did dissimilar interruptions. If WM is fully displaced by the interruption task, LTM remains the only means available to reinstate the pre-interruption situation. Two retrieval cues that may be especially useful when probing LTM are a temporal cue and a context cue. The point at which the two cues intersect is at the point of the interruption, which would then allow reinstatement of the pre-interruption situation. However, if either one of the cues fails to access the appropriate information, the interruption will succeed in producing a lack of memory for what occurred prior to the interruption.

The common thread among these interruption studies is that all have found poorer memory for the main task if the main and interruption tasks were similar than if they were dissimilar. However, it is apparent that the definition of similarity varied across experiments. For example, Czerwinski, et al. (1991) describe similarity as shared materials, whereas Gillie and Broadbent (1989) describe similarity as the memory-intensiveness of the interruption. What is needed is a way to specify the relationship between the main task and the interruption so the effects on memory are clear.

Length. Gillie and Broadbent (1989) concluded that interruption length had no effect on memory for the main task. However, subjects completed only 30 s of mental arithmetic. Perhaps a longer interval would produce a decrement in performance. On the other hand, personal experience tells us that sometimes even shorter interruptions produce drastic effects on memory for the main task. Thus, it may not matter how much time the interruption takes, but what is done during that time.

A similar point has been made in the prospective memory literature. Prospective memory refers to memory for things to be done in the future (e.g., take medication before bed). In a typical study, subjects were told to remember to perform a particular action after completing an intervening task. The primary measure was whether or not subjects remembered to perform the prospective action. In one study (Wilkins, 1976), subjects were given cards to return to the experimenter after either 2 or 36 days. He found no effect of interval length on performance. A study by Meacham and Columbo (1980) required subjects to hold up a placard within 10 s of specific times (and not before). Subjects watched a movie; the only clock was directly opposite the television. Subjects sometimes looked at the clock as few as 10 s before the appointed time, yet they still forgot to hold up the placard. Apparently, the movie was distracting enough to cause forgetting even after 10 s. Clearly, what you are doing is more important than the time it takes to do it. How might we classify "what you are doing" in the context of the relationship between the main and the interruption tasks?

Complexity. Gillie and Broadbent (1989) found that interruption complexity had a disruptive effect on memory for the main task. The interruption consisted of a coded math task in which A=1, B=2, etc. The support of LTM may be what Gillie and Broadbent referred to as cognitive effort: the effortful process of interruption recovery following a complex interruption.

Warning. Czerwinski et al. (1991) examined the effects of warning subjects of an upcoming interruption on the ability to remember characteristics of the main task. A warning may enable the subject to better encode what they are doing, or to reach a "stopping point" before the interruption occurs. Czerwinski et al. found no effect of warning. However, this may have been due to the way subjects were instructed. All were told that at any time during the experiment, the mission control director might ask them for specific information. This may have caused all subjects to encode the material in a state of constant preparation for the interruption, eliminating any effect of a warning.

In Gillie and Broadbent (1989) and Kreifeldt and McCarthey (1981), the interruption was repeated within-subjects. When a subject is interrupted more than once it may act as a warning and change the way the main task is encoded. Unless the goal is to determine the effect of interruption warning, each subject should be interrupted only once.

Each of the preceding interruption characteristics could potentially impact the ability to remember what occurred prior to the interruption. However, the conditions under which each characteristic results in reduced memory performance remains the responsibility of empirical investigation. This dissertation focuses on interruptions that share materials with the main task because it is one case in which similarity is well defined. The goal is to set boundary conditions that determine when interruption-similarity (defined as sharing materials) will lead to a lack of memory for the main task.

As previously mentioned, another variable that may influence interruption recovery is the degree of familiarity with the main task. Each of the studies mentioned above used subjects that were relatively unfamiliar with the task from which they were interrupted. If subjects are allowed to familiarize themselves with the main task, thereby forming an integrated long-term memory representation, the interruption-similarity effect may be reduced or possibly eliminated. To understand why this might be the case, we next examine possible differences between the memory representation for routinized and nonroutinized tasks.

Familiarity and Changes to the Memory Representation

Hayes-Roth (1977) proposed that changes occur to the cognitive representation as familiarity increases. She developed the Knowledge-Assembly theory to describe these changes. Learning begins with the establishment of memory representations of the elementary components of a task. Once established, these are activated individually, given a stimulus containing the proper components. With additional experience these elementary representations become stronger and relational associations are established among them. A configuration of related representations is activated by means of excitation spreading from one configuration to another along the associative connections. Ultimately, a configuration can be strengthened to the point of "unitization." The configuration then acts as an all-or-none activatable memory representation. "Thus, over the course of an individual's experience with a knowledge structure, the memory representation of that structure is assumed to progress hierarchically from a collection of independent but related parts, to a single, integrated representation of the structure as a whole" (p. 261).

Bullemer and Nissen (1990) demonstrated a progression from a representation containing individual components to one containing relational associations. They trained subjects using either a random or structured sequence of light flashes. Early in training, they found that random and structured sequences were recalled equally well, suggesting the individual cognitive components had been established. After several additional trials, subjects given the structured sequence could accurately generate the next item in the sequence; subjects given the random sequence could not. The cognitive representation of the structured group apparently contained associative connections that the random group did not. Thus, learning a structured sequence resulted in a change to the memory representation that led to a noticeable change in performance.

Familiarity and Changes in Performance

Performance typically evolves from a difficult, totally consuming task to one that seems very easy and requires little concentration. For example, learning to drive a vehicle with a manual transmission requires a great deal of effort and concentration. Listening to an instructor, remembering how to shift gears, staying in the correct lane, and maintaining awareness of the traffic situation, seem like an overwhelming task at first. After several years of experience, however, these tasks that once seemed complex barely enter into consciousness and are said to be automatized (Schneider & Shiffrin, 1977).

A framework related to the Hayes-Roth's (1977) Knowledge-Assembly theory has been proposed by Rasmussen (1983, 1986) to describe how humans control their behavior. His SRK model consists of three modes of control: (1) *Skill-based*, (2) *Rule-based*, and (3) *Knowledge-based*. The *Skill-based* level comprises highly organized and well-practiced activity. The actions that belong to this level are assumed to be "unitized" because once they are activated they cannot be blocked. An example of *skill-based* behavior is the experienced driver mentioned above. "Performance is smooth and integrated...and the senses are only directed toward the aspects of the environment that subconsciously update the internal map" (Rasmussen, 1986, p. 101).

The *Rule-based* level includes actions that are performed according to a set of rules. In contrast to *Skill-based* behavior, *Rule-based* behavior is dependent upon explicit knowledge and rules that can be verbally reported by the person. Changing a flat tire is an example of a rule-based behavior.

The *Knowledge-based* level is adopted to cope with unfamiliar situations where previously stored rules are not sufficient. For example, while traveling abroad you rent a car to go see a friend and realize that you must drive in the left-hand lane, the steering wheel is on the right-hand side of the car, and the primary controls are on the driver's left. This situation requires a great deal of cognitive effort because the "driving rules" that you have developed no longer apply.

In the SRK framework, behavior evolves from a trial-and-error process (*Knowledge-based*) to a process in which the behavior occurs without intention (*Skill-based*). Similar distinctions between different categories of human behavior have previously been proposed. Fitts and Posner (1962) hypothesized three phases of skill learning: the early cognitive phase, the secondary associative phase, and the final autonomous phase. The SRK framework has been successfully used in error classification (Reason, 1987) and in examining the mechanisms that underlie the detection of errors (Rizzo, Bagnara, & Visciola, 1988).

Combining the Models

The Knowledge-Assembly theory of Hayes-Roth (1977) and the SRK framework of Rasmussen (1982, 1983) are similar in several respects. Both models assume a three-stage learning process. The lowest level involves the development of individual cognitive components (Hayes-Roth) each representing a unitary concept (Rasmussen). The next level includes associative connections among the components (Hayes-Roth) that are established by continually executing a stored rule (Rasmussen). The highest level consists of an all-or-none activatable cognitive unit (Hayes-Roth), resulting in smooth and integrated performance occurring without attention or conscious control (Rasmussen). Thus, at each level the combined model specifies the cognitive representation as well as the resulting change in performance.

The combined model predicts that learning a task having a fixed order of components will establish associative connections between each component. This will result in increased speed of completion and the ability to generate the next component in the sequence. However, making the order of task components arbitrary across learning trials should eliminate associative connections between components, resulting in no speed-up in completion time and an inability to generate the next component in the sequence. If the contents of WM has been eliminated by the interruption task, there should be little (if any) memory for the main task.

On the other hand, a cognitive representation with associative connections should be less affected by an interruption than a representation containing individual components. The connections among the components may enable LTM to generate the information necessary to recover from the interruption and reinstate the pre-interruption situation.

Overview of Experiments

The purpose of the following experiments was to examine the effect of interruption similarity on fixed and arbitrary task sequences. Subjects performed a main task similar to that used by Gillie and Broadbent (1989) in which items were retrieved from several locations within a hypothetical town (see Figure 1). Each subject retrieved six, ten-item lists. The nature of the memory representation was manipulated by either fixing or randomizing the order in which items were retrieved. According to Hayes-Roth (1977), associative connections should be established among the items learned by the Fixed group, but not the Arbitrary group. The strength of these connections (Nissen & Bullemer, 1991) may allow the subject to access memory faster and more accurately, thereby reducing or eliminating the usual detrimental effect of a similar interruption found in previous research.

Insert Figure 1 about here

Unbeknownst to the subject, they would be interrupted halfway through the sixth list. Unlike previous research (e.g., Gillie & Broadbent, 1989) each subject experienced only one interruption, thereby ensuring that none of the interruptions were anticipated. Immediately after being interrupted, subjects were queried regarding where they just visited and what they were about to retrieve before being interrupted. If associative connections are established in the fixed group, they should be able to respond faster (Logan, 1988) and more accurately (Hayes-Roth, 1977) than the randomized group regarding what they were *about to* retrieve.

To replicate the interruption-similarity effect, the similar interruption should result in poorer performance than a dissimilar interruption. Interruption similarity should increase the interference that must be overcome following the interruption. Overcoming this interference should be difficult for the Arbitrary group, resulting in the interruption-similarity effect.

We also manipulated the memory test, either recognition or recall. After completing the interruption task, a subject was given a list of items or locations in the recognition condition, or was required to respond from memory only in the recall condition. This manipulation was included to determine whether explicit cues would overcome the interference caused by a task-similar interruption. Thus, there were three variables manipulated in Experiment 1: order of the items (fixed or random), interruption type (similar or dissimilar), and memory test (recall or recognition). The Fixed group should be unaffected by the interruption, regardless of similarity, but the Arbitrary group should reveal the interruption-similarity effect. This effect should be revealed regardless of the type of memory question (location just visited or item to be retrieved).

Before beginning Experiment 1, a norming study was conducted to determine which items and locations to use. We needed a set of items each of which could only be retrieved at one of the possible locations.

Norming Study

Method

Subjects. Participants were 150 students from the Introductory Psychology pool at the University of Oklahoma who participated in partial fulfillment of a course requirement.

Design. A list of 22 locations was generated, together with 3 or 4 items likely to be found at each location. For example, the items at the Computer Store included a monitor, floppy disks, a modem, and a keyboard; the items at the Jewelry Store included a ring, bracelet, watch, and necklace. A sheet was prepared with the locations on the left and the items on the right. The list was distributed to a classroom of students who were instructed to place each item by the location that first came to mind. Each item was to be listed beside a location, but not all locations had to contain items.

Results

Fifteen locations were selected that contained two highly probable items. One of these items was used in the main task for Experiments 1 and 2; the other item was needed for the similar interruption task of Experiment 1. Four locations served as fillers and no items were selected that could be retrieved from these locations (Home, Church, Police Station, and Firehouse). The locations, items, and percentage of time each item was mentioned at that location, are given in Table 1. Three locations were dropped (Car Dealer, Beauty Shop, Restaurant) because there was substantial disagreement over the items listed at these and at least one other location (e.g., motor oil could be found at both the Gas Station or the Car Dealer).

Insert Table 1 about here

The materials selected in the Norming study were then used as items and locations for Experiment 1. Subjects retrieved each item by issuing a sequence of commands as they moved through the map.

Experiment 1

Method

Subjects. Participants were 128 students from the Introductory Psychology pool at the University of Oklahoma who participated in partial fulfillment of a course requirement.

Materials. Materials consisted of the 19 locations and 30 items obtained from the norming study. Half of the items were used for the main task and half were used for the task-similar interruption.

Design. The design was a 3-way between-subjects factorial. Each subject was randomly assigned to either the Fixed or Arbitrary group, received either a Similar or Dissimilar interruption, and was given either a Recall or Recognition test when the interruption was completed.

Procedure. Each subject was tested individually using an IBM-compatible personal computer. Upon entering the laboratory, each subject was given a map of the town (Figure 1) and informed that they would be retrieving items from the locations shown on the map. They would be completing six ten-item lists, and the items were to be retrieved in order. Before beginning the first list they were shown an example list of three items and the sequence of commands required to retrieve them.

For each subject, 10 items were randomly selected from the 15 possible. Subjects in the Fixed group retrieved the items in the same order on each list. Subjects in the Arbitrary group retrieved the same set of items on each list, but in a different random order each time.

At the beginning of each list, the items were presented in the upper left-hand corner of the screen. When subjects felt that they had sufficiently memorized the list, they pressed any key to begin retrieving the items. The map shown in Figure 1 appeared in the upper 3/4 of the screen and remained there as they retrieved the items on their list. As they moved through the map they had to keep their present location in memory: nothing changed on the monitor. At any time the subjects could press *'I'* to review the list for 10 s; the map was not visible during this time. Upon completing the list, they were to write down, *in order*, the items they had just retrieved.

The following rules applied as they navigated through the map:

1) *Home* was the starting point for every list.

2) To move, subjects typed the first letter of the desired direction of movement (up, down left, right), and then the name of the location.

3) Only 90 movements could be made (e.g., you could not go from the Bank to the Jewelry Store, without going through the Computer Store).

4) Only streets running left-to-right could be crossed (e.g., you could not go directly from Home to the Liquor Store, but had to go to the Jewelry Store, Hardware Store, Post Office, and then the Liquor Store).

5) Locations could not be skipped (e.g., to get from the Jewelry Store to School, you had to go through the Hardware Store and the Post Office).

6) To retrieve an item, they typed 'R' and the name of the item to be retrieved.

Subjects were told that the goal of the experiment was to see how quickly and efficiently a group of items could be retrieved. They were told to minimize the number of times they looked back at the list, but not to forget an item or get one out of order. Subjects were interrupted after retrieving the fifth item on List 6.

Interruption. Immediately upon retrieving the fifth item on List 6, the computer beeped and displayed a message indicating that this part of the experiment was over. The experimenter entered the room and reiterated that this part of the task was now complete and gave the subject either a task-similar or task-dissimilar interruption to complete. The interruption lasted 3 min.

For the task-similar interruption, subjects were given a sheet of paper containing the map of the town at the top and a new list of 15 items (those listed second in Table 1) at the bottom. They were to arrange the items so they could be retrieved most efficiently (i.e., minimize backtracking). For the task-dissimilar interruption, subjects were given a sheet of paper containing the map of the town at the top. At the bottom of the sheet was a 5x10 matrix of 2-digit integers. They were to sum the numbers in each row, placing the total at the end of the row. After summing each row, they were to sum the row totals to arrive at a grand total. They were to perform the addition on the sheet of paper and to show all work.

After three minutes elapsed, the computer beeped and the experimenter removed the interruption task and instructed the subject to return to the computer. When a key was pressed, the memory tests began.

Memory Tests. The memory tests consisted of an anticipatory memory test and a retrospective memory test. The anticipatory memory test was; "When the computer beeped the first time, you had just picked something up and were on your way to get something else. What was that something else?". The retrospective memory test was; "When the computer beeped the first time, you were at a particular location. What was that location?" The questions were always asked in this order.

Subjects in the Recall condition received only the questions. For the anticipatory question, subjects who were in the Recognition condition were given an alphabetized list of the 15 items (10 of which were those they were retrieving). For the retrospective question, subjects were given an alphabetized list of the 19 locations. Subjects typed in their answer, and the time to make the initial keypress was recorded.

Complete Main Task. Upon completion of the memory tests, subjects returned to the main task and finished retrieving the last five items from List 6. They began at the location that they indicated in the retrospective memory test and continued as before. After completing List 6, a map recall test was given.

Map Recall. Subjects were asked to reconstruct the town by drawing and labeling each location in its appropriate spatial position on a blank sheet of paper. They were given as much time as necessary to complete this task. When they felt they were done, they were debriefed and dismissed.

Results and Discussion

The Recall/Recognition manipulation had no reliable effect on any of the dependent measures and will not be discussed further. All effects discussed below are significant at $p<.05$, unless otherwise indicated. All post-hoc comparisons controlled the probability of a Type I error by dividing α by the number of comparisons (Dunn, 1961).

The number recalled without respect to order is a measure of the first level of representation of the Knowledge-Assembly theory because it is based on the retrieval of individual cognitive components; the number recalled in order is a measure of the second level because associative connections must be retrieved to provide order information. To demonstrate that the primary difference between the groups was their memory for the order in which the items were retrieved, Figure 2 gives the list recall results scored for *number* and *order* recall.

Insert Figure 2 about here

The Fixed group remembered a greater number of items than the Arbitrary group, $F(1,120) = 7.58$, and this changed as a function of learning, $F(5,116) = 4.33$. However, post-hoc comparisons showed no reliable difference in the *number* of items recalled after completing Lists 1 through 5 (Fixed $M = 9.7$, Arbitrary $M = 9.3$). Both groups were equally familiar with the items that they were retrieving prior to the interruption.

The next step was to show that the memory representation of the Fixed group included associative connections between elementary components whereas the memory representation for the Arbitrary group did not. Based on the assumption that sequential order is maintained by associative connections (Lee & Estes, 1977), the list recall results were scored for *order*. Recall *order* was scored by assigning a point to each word recalled in proper sequence. Thus, if someone recalled only three items, all in their proper order, they would get three points; if two were switched, they would get only one point. As shown in the bottom panel of Figure 2, the Fixed group outperformed the Arbitrary group, $F(1,126) = 16.68$. There was also an effect of list number, $F(5,122) = 7.69$, as well as an interaction, $F(5,122) = 5.77$. Post-hoc tests showed that recall order did not differ between groups on Lists 1 through 3; recall order on Lists 4 and 5 was better for the Fixed group ($M = 9.6$) than for the Arbitrary group ($M = 8.0$). It appears that the primary difference between the groups was their familiarity with the *order* of the items, and consequently, in the existence of associative connections among the elementary components for the Fixed group.

The anticipatory memory results are shown in the upper panel of Figure 3. The Fixed group remembered more than the Arbitrary group, $\chi^2\,(1) = 7.33$. This pattern was unaffected by interruption type. The performance of each group was compared to chance (.10) using a normal approximation to the binomial distribution (Hays, 1988), and controlling α at .006 (.05 / the number of tests). The similar interruption resulted in chance performance for the Arbitrary group, $z = 2.2$, but performance was above chance following a dissimilar interruption, $z = 4.6$. The Fixed group performed above chance regardless of interruption type (smallest $z = 7.5$). Above chance performance following a dissimilar interruption and chance performance following a similar interruption define the interruption similarity effect.

Insert Figure 3 about here

Each subject was next asked which location they were visiting when they were interrupted. This is referred to as the retrospective memory task. The retrospective memory results are shown in the lower panel of Figure 3. For the Arbitrary group, performance was above chance (.05) for both types of interruption (smallest $z = 5.0$). However, the similar interruption significantly reduced performance relative to the dissimilar interruption, χ^2 (1)= 4.47. Interruption type had no effect on the Fixed group, χ^2 (1) = .0001, p=1.0; performance was above chance regardless of interruption type (z = 13.7). The fact that performance for the Arbitrary group on both the anticipatory and retrospective tasks was worse after the similar interruption is consistent with past research (Czerwinski, et al., 1991; Gillie & Broadbent, 1989; Kreifeldt & McCarthey, 1981). Performance of the Fixed group was unaffected by the type of interruption and was generally superior to the Arbitrary group. We believe that the superior performance is the result of the associative connections engendered by the fixed presentation order. The lack of any effect of interruption type is consistent with related findings in the memory literature. For example, Hockley (1991, 1992) found that memory for associations between randomly paired words was more resistant to the effects of decay and interference from intervening events than is memory for individual words (akin to Hayes-Roth's individual component level). Hockley attributes this lack of forgetting to the distinctiveness that associations provide and individual words do not.

Additional variables were analyzed to better understand the nature of the interruption-similarity effect for the Arbitrary group and the lack of such an effect for the Fixed group. The first of these was the missed distance between the actual and recalled locations. The actual location was the location they were currently visiting when they were interrupted and the recalled location was their response to the retrospective memory question (the location they thought they had been visiting). The missed distance was computed by determining the fewest number of moves required to get from the actual location to the one recalled. For example, if the actual location was the Bakery and they recalled the Hardware Store, the missed distance would be 5. As shown in Figure 4, the Fixed group recalled a location approximately one move away from the current location, regardless of interruption type. This was also true for the Arbitrary group following a dissimilar interruption; after a similar interruption the missed distance was approximately 2.4 moves, $F(1,124) = 6.28$. This pattern necessarily mimics the retrospective memory data. It shows that even though subjects did not remember exactly where they were, they were able to get quite close.

Insert Figure 4 about here

Memory Task Latency. We examined the latency to respond for each memory task. The latency for the anticipatory memory task is shown in the top two lines of Figure 5. The Fixed group responded more quickly than the Arbitrary group, $F(1,124) = 8.90$, and the similar interruption resulted in longer latencies than the dissimilar interruption, $F(1,124) = 4.40$, although this was primarily true for the Arbitrary group.

The interaction was not significant. The long response times indicate that these were far from automatic responses for the subjects.

Insert Figure 5 about here

The lower two lines in Figure 5 show the time to respond to the retrospective memory test. There was no difference due to group membership, $F(1,124) = .88, p > .10$, nor interruption type, $F(1,124) = .01, p > .10$. The anticipatory task latencies were slower overall than the retrospective latencies, probably because it was the first question asked after the interruption. The anticipatory task latencies would be a combination of the time to return to the main task, plus the time to generate the next item in the sequence.

we present additional training data to further support that the Fixed and Arbitrary groups differed only in their familiarity with the *order* of the items. Both groups should issue approximately the same number of commands on each list and the number of commands should be close to the optimal number. In addition, the number of locations recalled during the map recall task should not differ. Finally, because the Fixed group always retrieved the items in the same order, they should spend less time studying each list, should complete a list in less time, and should look back at a list fewer times after beginning to retrieve the items.

The number of commands to complete a list remained relatively constant at approximately 46, irrespective of group membership or list number. Command efficiency scores were calculated by subtracting the minimum number of commands necessary to complete the task from the actual number of commands issued. Positive scores indicated that more commands were issued than necessary; negative scores indicated that fewer commands were issued than necessary (i.e., an error was made and some moves were skipped). There was no difference between the groups in command efficiency, $F(1,126)$

= .01, $p > .10$. Both groups performed within two commands of optimal throughout training.

We also examined memory for the spatial arrangement of the map using the map recall task. Performance was quite good, especially considering that subjects were never explicitly asked to learn the map. As shown in Table 2, there was no effect of group membership, $F(1,124) = 1.06$, $p > .10$, nor interruption type, $F(1,124) = .59$, $p > .10$. Of those locations not remembered, most (92%) were locations that did not contain one of the 10 items on their list.

Insert Table 2 about here

The amount of time each group spent studying a list during the initial study phase is shown in Figure 6. The Fixed group spent less time studying a list than the Arbitrary group, $F(1,126) = 21.89$. Study time also decreased as a function of list number, $F(5,122) = 14.35$, and the interaction was significant, $F(5,122) = 3.66$. Post-hoc comparisons showed no between-group differences on Lists 1 or 2, but the Fixed group spent less time studying Lists 3 through 6.

Insert Figure 6 about here

The time to complete each list is shown in Figure 7. Completion time for List 6 was corrected by subtracting the time to complete the interruption (3 minutes) and the time to complete each memory task. The Fixed group took less time overall to complete each list, $F(1,126) = 17.79$, and completion time decreased as a function of list number, $F(5,122) = 301.01$. The interaction was also significant, $F(5,122) = 4.26$. The longer list completion times for the Arbitrary group were due in part to more times reviewing the list while retrieving the items.

Figure 8 shows that the Fixed group reviewed the list less often overall, $F(1,126) = 102.6$. The number of looks decreased with list number, $F(5,122) = 28.98$, although this was due entirely to the Fixed group. Post-hoc tests showed that both groups looked back equally often on List 1, $t(126) = .23$, $p>.10$. For the Fixed group, there was a significant drop in the number of looks between Lists 1 and 2, and again between Lists 2 and 3, but no changes on Lists 3 through 6. The only significant change for the Arbitrary group was an increase at List 6, $t(62) = 3.54$. This is consistent with the idea that the interruption had a greater effect on the memory of the Arbitrary group.

Insert Figures 7 and 8 about here

We split the number of looks back during List 6 into those occurring pre- and those occurring post-interruption There is an increase in the post-interruption looks for the Arbitrary group (Pre = .9, Post = 2.4), $t(63) = 9.36$, but no significant increase for the Fixed group (Pre = .02, Post = .06), $t(63) = 1.14$, $p>.10$. A floor effect may account for the lack of a pre- post-interruption effect for the Fixed group.

Summary

These data show that the similarity effect found in previous interruption studies does not hold when the order in which the task is performed is highly familiar. This suggests that training on a task that results in the storage of associative connections allows better memory both for what has already been completed and what is still left to do, and is relatively resistant to interference in the form of a task-similar or task-dissimilar interruption. When training on a task does not result in the storage of associative connections, memory for what has already been completed and what is still left to do is worse following a task-similar interruption than following a task-dissimilar interruption. These data indicate that LTM may play a role in interruption recovery. After completing the interruption the Fixed group can utilize LTM and generate the information necessary to overcome the interruption. The lack of LTM support for the Arbitrary group reduces the effectiveness of LTM, thereby increasing the disruptive effect of the interruption.

Experiment 2 sought to replicate these results while eliminating two uninteresting explanations of the differential effect of the similar interruption in the Arbitrary group. First, the order in which the questions were asked might be responsible; the anticipatory question was always asked first. The response to the anticipatory question could create demand characteristics causing subjects to respond differently than they would have if the retrospective question were asked first. Another possibility has to do with the particular task-similar interruption that was used, which had subjects working with the locations that they would later be asked about, but not the specific items. For that reason, the similar interruption might be especially detrimental to the retrospective memory location task.

Experiment 2 used the same procedures as Experiment 1 but included only the Arbitrary group. They were the only group affected by interruption type. The only change from Experiment 1 involved the task-similar interruption. In Experiment 2, the task-similar interruption involved the specific *items* that the subjects would later be asked to retrieve. If the task-similarity effect found in Experiment 1 was due to the particular location-based interruption, a different task-similar interruption involving the items should harm performance on the anticipatory memory item task but not the retrospective memory location task. On the other hand, if the Experiment 1 finding were not due to the particular interruption, performance on the retrospective location task should be harmed, leaving the anticipatory memory item task unaffected.

Experiment 2

Method

Subjects. Participants were 66 students from the Introductory Psychology pool at the University of Oklahoma who participated in partial fulfillment of a course requirement.

Materials. The materials were identical to those used in Experiment 1.

Design. The design was a one-way between-subjects factorial. Each subject retrieved the same ten items in a different random order on six lists, and received either a task-similar or task-dissimilar interruption in the middle of List 6.

Procedure. The procedure was identical to that of Experiment 1 except for three changes. First, during the task-similar interruption, subjects were given a list of 15 items made into anagrams (see Table 3). They were told that some of the anagrams were items that they had been retrieving (in fact 10 of them), and that they were to solve them by writing the solution beside the anagram. The second change was that the order in which the memory tests were administered was randomized. After completing the interruption, half of the subjects completed the anticipatory task first and the other half completed the retrospective task first. The third change was that following these two questions, subjects were asked an additional retrospective item-based question about the item they had retrieved before the interruption. If the interference due to the interruption task was specific to the material used in the interruption, the interruption-similarity effect should manifest itself in both the anticipatory item task and the retrospective item-based task by reduced performance following a similar interruption as opposed to a dissimilar interruption. If, on the other hand, the interference due to the interruption was not dependent on the use of shared materials, then the interruption-similarity effect should show up as before in the retrospective memory task.

Insert Table 3 about here

Results and Discussion

To demonstrate that subjects were familiar with the list items but not their order, the list recall data were scored for *number* and *order* correct. The *number* of words recalled did not change across lists ($M = 9.4$), $F(5,60) = .67$, $p > .10$. An ANOVA revealed a change in recall *order* across lists ($M = 8.3$), $F(5,60) = 3.57$, but post-hoc comparisons found no reliable differences. These results were similar to the Arbitrary group in Experiment 1 (number recalled = 9.3, order recalled = 8.0).

The anticipatory memory results are shown in the upper panel of Figure 9. Performance was not different from chance when the anticipatory memory task was followed by a similar interruption, $z = 2.2$, but was above chance with a dissimilar interruption, $z = 4.6$. Performance on the retrospective task was above chance for both interruption types (smallest $z = 8.9$), but a similar interruption resulted in poorer memory than a dissimilar interruption, , $\chi^2(1) = 6.11$ (see lower panel of Figure 9). These results replicate Experiment 1 and demonstrates that the results were not due to the location-based interruption nor to the order in which the memory tasks were administered.

Insert Figure 9 about here

We computed the missed distance for the location-based retrospective task. As shown in Figure 10, a similar interruption resulted in the recall of a location approximately 2.3 moves away from the actual location, but this decreased to .9 when the interruption was dissimilar, $t(64) = 2.56$.

Insert Figure 10 about here

Memory for the spatial arrangement of the map did not differ with interruption type, $t(64) = .07, p > .10$. Both groups recalled approximately the same number of locations ($M = 15.8$). For those locations that were not remembered, the majority (84%) were locations that did not include any of the 10 items on their list.

Memory Task Latencies. Latencies for each of the memory tasks are shown in Figure 11. Latency to respond to each memory test changed as a function of the test, $F(2,63) = 8.37$, but there was no interaction with interruption type, $F(2,63) = .26, p > .10$. Post-hoc comparisons showed no difference between the anticipatory and the retrospective memory tasks, $t(65) = 1.71, p > .05$. The increased latency for the anticipatory task in Experiment 1 did not replicate; it was apparently due to the order in which the memory tasks were given.

Insert Figure 11 about here

Training. The training data should show little change in performance across lists. The number of commands to complete each list decreased with list number, $F(5,60) = 3.45$, but this was due to the decrease from approximately 49 commands on List 3 to approximately 45 commands on List 4. It took an average of 47 commands to complete each list. Command efficiency scores were calculated as in Experiment 1. The number of commands did not reliably depart from optimal, $F(5,60) = .78, p > .10$. Subjects did not issue any unnecessary commands at any time during training.

The time spent studying each list during the initial study phase showed no effect of list number, $F(5,60) = 1.16, p > .10$. Time to complete each list is shown in Figure 12.

Completion time for List 6 was corrected by subtracting out the time to complete the interruption (3 minutes) and the time to complete the memory tasks. The amount of time spent retrieving each list decreased as subjects became more familiar with the task, $F(5,58) = 13.80$. Post-hoc comparisons showed a significant decrease in completion time between Lists 2 and 3, and between 3 and 4, with no additional decrease on List 5. Completion time then increased on List 6.

Insert Figure 12 about here

The number of times subjects looked back at the list while retrieving the items is shown in Figure 13. The number of looks changed as a function of list number, $F(5,60) = 9.02$. Post-hoc tests showed a decrease between Lists 1 and 2, and another between Lists 3 and 4. As in Experiment 1, there was an increase in the number of looks between Lists 5 and 6. The number of looks back during List 6 was split into those occurring pre- and post-interruption. Although there was no effect of interruption type, $F(1,64) = .41$, $p > .10$, the number of post-interruption looks ($M = 2.8$) exceeded the pre-interruption looks ($M = 1.0$). These last two results demonstrate the disruptive effect of the interruption on the Arbitrary group.

Insert Figure 13 about here

Overall, Experiment 2 showed that the results obtained in Experiment 1 were not due to the specific nature of the task-similar interruption, and were not due to the order in which the memory questions were asked.

General Discussion

The experiments reported here examined the effects of task-similar and task-dissimilar interruptions on familiar or unfamiliar tasks. The organization of the memory representation was manipulated by learning either a fixed or arbitrary sequence of items. Performance for the Fixed group was relatively immune to the interfering effects of the task-similar interruption, however, performance for the Arbitrary group was quite different. Retrospective memory was significantly impaired by a task-similar interruption but not a task-dissimilar interruption; anticipatory memory was unaffected by interruption type. Regardless of the type of interruption, a memory representation with well-established associative connections, supports recall of the events that have already taken place, as well as those events yet-to-be-performed. On the other hand, a memory representation of individual components with no associative connections is more affected by task-similar interruptions than task-dissimilar interruptions. This occurred regardless of whether the memory task involved events that had already taken place or events yet-to-be-performed. These data support Hockley (1991, 1992) who showed that associative information is relatively resistant to interference but occurrence information is not.

Individual components organized in LTM by associative connections can provide a great deal of information that individual components alone cannot. After completing the interruption, the Fixed group can use this associative information to generate the proper cues to help reinstate the pre-interruption situation. Two possible cues are context and temporal order. The point on which these two cues intersect is the point at which the interruption occurred, providing a starting point from which to search for the required information.

Associative information was not available to the Arbitrary group, which significantly reduced the effectiveness of LTM in helping to reinstate the pre-interruption situation. The individual components may be limited to only the context cue which defines a much broader starting point from which to search for the required information.

It is interesting to note that following a dissimilar interruption, the Fixed and the Arbitrary group did equally well on the retrospective memory task, but there was a relatively large difference in performance on the anticipatory memory task. This may indicate that memory for events that have been completed is qualitatively different from events that are yet-to-be-performed. The idea that anticipatory and retrospective memory performance are uncorrelated has also been observed in the prospective memory literature (e.g., Einstein & McDaniel, 1990; Kvavilashvili, 1987; Maylor, 1990). For example, Einstein and McDaniel (1990) found that prospective memory performance was uncorrelated with the recall or recognition of words experienced during a period of interpolated activity that separated the prospective command from its execution. Perhaps decisions based on anticipatory or retrospective memory rely on different processes.

These data may be of particular interest to those involved in education or training. Early in training, when trainees are initially familiarizing themselves with a task, interruptions may be especially disruptive because the memory representation only contains individual components of the task. As task familiarity increases, however, interruptions may have less of an impact because of the increased organization of the memory representation. It is possible that continual interruptions in the early stages of training may slow the training process because it would slow the establishment of associative connections.

We assume that none of the groups in the experiments reported here achieved the highest, or *skill-based*, level of performance. Performance at this level is characterized by an all-or-none activatable memory representation (Hayes-Roth). It is possible that additional training would result in this type of representation, and that subjects could complete the list "automatically." Hayes-Roth suggested that once this type of representation was activated it was completed and could not be blocked. This implies that a unitized task could be efficiently time-shared with another task with little, if any, decrement in performance.

Interrupting performance at this level may be especially harmful. For example, in the Air Traffic Control domain, controllers tend to perform particular sets of actions as the plane leaves the airspace. Vortac (in press) and Vortac, Edwards, Fuller, and Manning (in press) suggested that these actions were modularized (synonymous with unitized) because the sequence occurs so frequently and always in the same fixed order. This type of representation may lose any temporal character because it has become so highly integrated. We might expect memory for the main task to be significantly impaired when the interruption comes in the middle of a "module."

As the memory representation evolves from the establishment of individual components (knowledge-based) to the inclusion of associative connections (rule-based) to the final "unitized" (skill-based) level, memory performance may take the form of an inverted-U. In the early stage, the memory representation is characterized by a collection of individual components lacking organization and coherence. During this stage, memory is unstable and easily affected by interference caused by an interruption. The second stage establishes organization and dependence among the components in the form of associative connections. This type of representation is resistant to the interfering effects of an interruption because of the contextual and temporal information provided by the organization. At the skill-based level, the temporal information may be inaccessible because activation automatically spreads from one component to the next. For this reason, a unitized representation may be unable to overcome the interfering effects of an interruption and result in performance similar to a task at the knowledge-based level.

A commonly used phrase is "a little bit of knowledge is a dangerous thing." However, if that little bit of knowledge is well-integrated and organized, and has not yet reached unitization, it may be optimal when interruptions are a common occurrence.

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Table 1

First and second most frequently listed items for each location in the Norming Study.

Location	Item	Likelihood	Location	Item	Likelihood
Bakery	bagel	100%	Jewelry Store	ring	98%
	bread	98%		necklace	98%
Candy Store	taffy	99%	Computer Store	floppy disks	100%
	jaw breakers	100%		modem	100%
Sporting Goods	sweatshirt	95%	Bank	money	98%
	football	98%		travelers checks	94%
Vegetable Market	broccoli	98%	Cleaners	starched shirt	99%
	cauliflower	97%		suit	95%
Pet Shop	dog	95%	Gas Station	fuel	99%
	cat	97%		oil	66%
Florist	roses	99%	Liquor Store	beer	86%
	tulips	100%		vodka	100%
School	grades	100%			
	children	73%			
Post Office	stamps	99%			
	mail	100%			
Hardware Store	pliers	95%			
	hammer	98%			

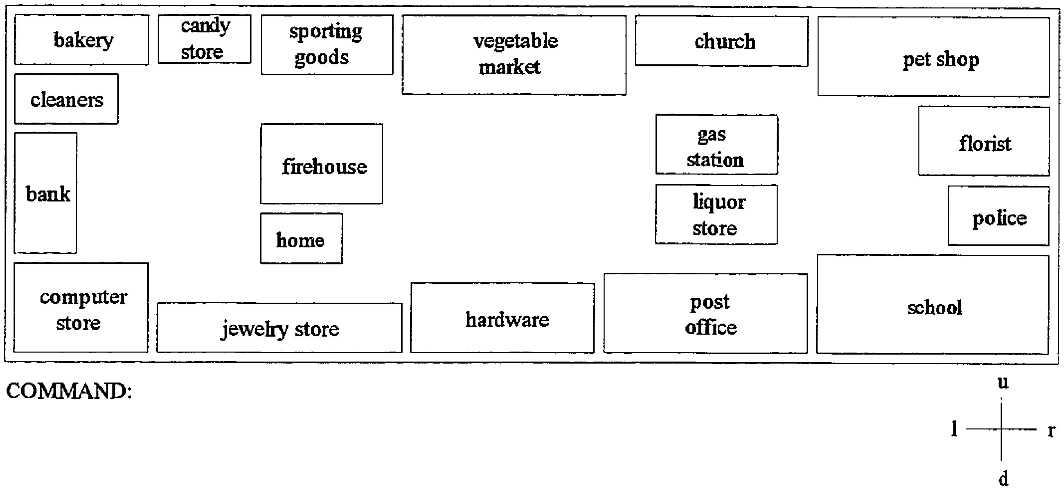
Table 2

Interruption Type	Similar		Dissimilar	
Order	Fixed	Arbitrary	Fixed	Arbitrary
Locations recalled	16.63	15.63	16.28	16.72

Table 3

Anagram	Solution
adrbe	bread
atsrehwistr	sweatshirt
ctrahsde tisrh	starched shirt
eagsrd	grades
faytf	taffy
grni	ring
locrbico	broccoli
mpatss	stamps
nyeom	money
odg	dog
pofply idkss	floppy disks
rebe	beer
rpiels	pliers
srsoe	roses
ulef	fuel

Figure 1



COMMAND:

Figure 2

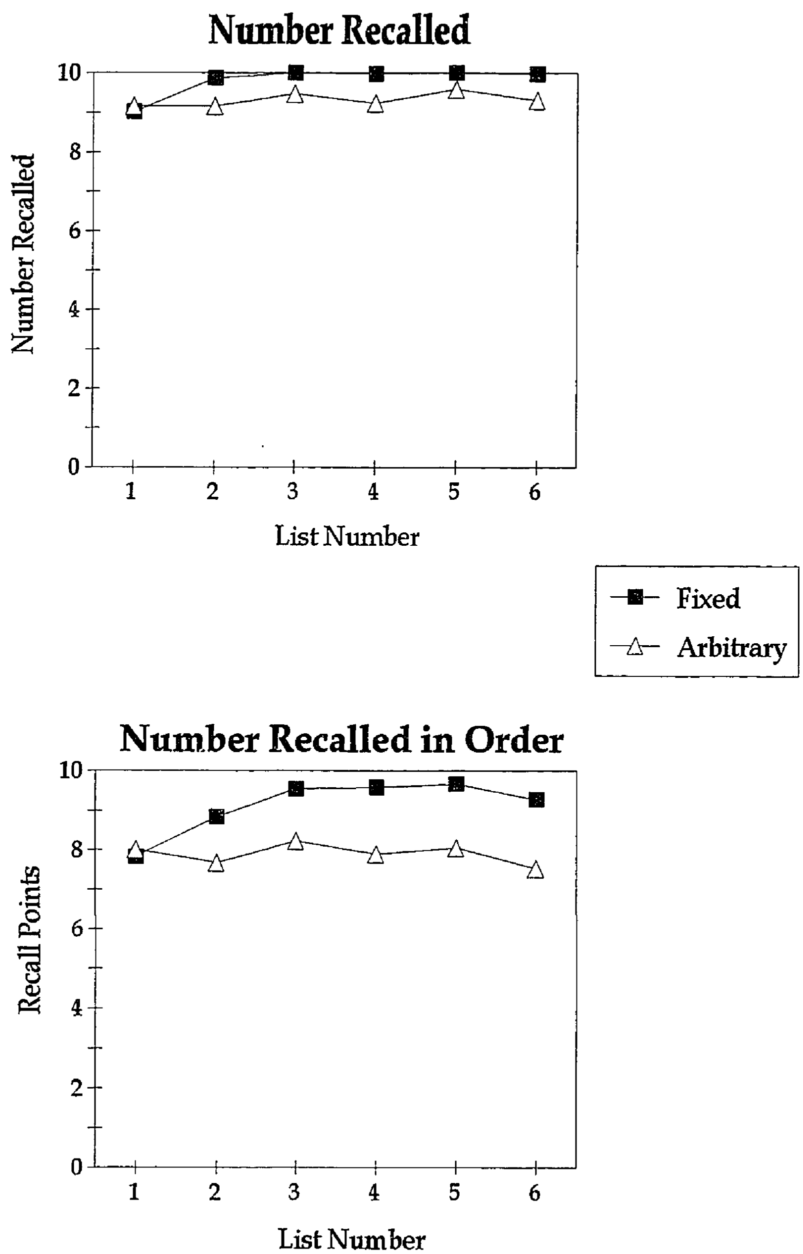

Number Recalled
Number Recalled
10
8
6
4
2
0
1
2
3
4
5
6
List Number
Fixed
Arbitrary
Number Recalled in Order
Recall Points
10
8
6
4
2
0
1
2
3
4
5
6
List Number

Figure 3

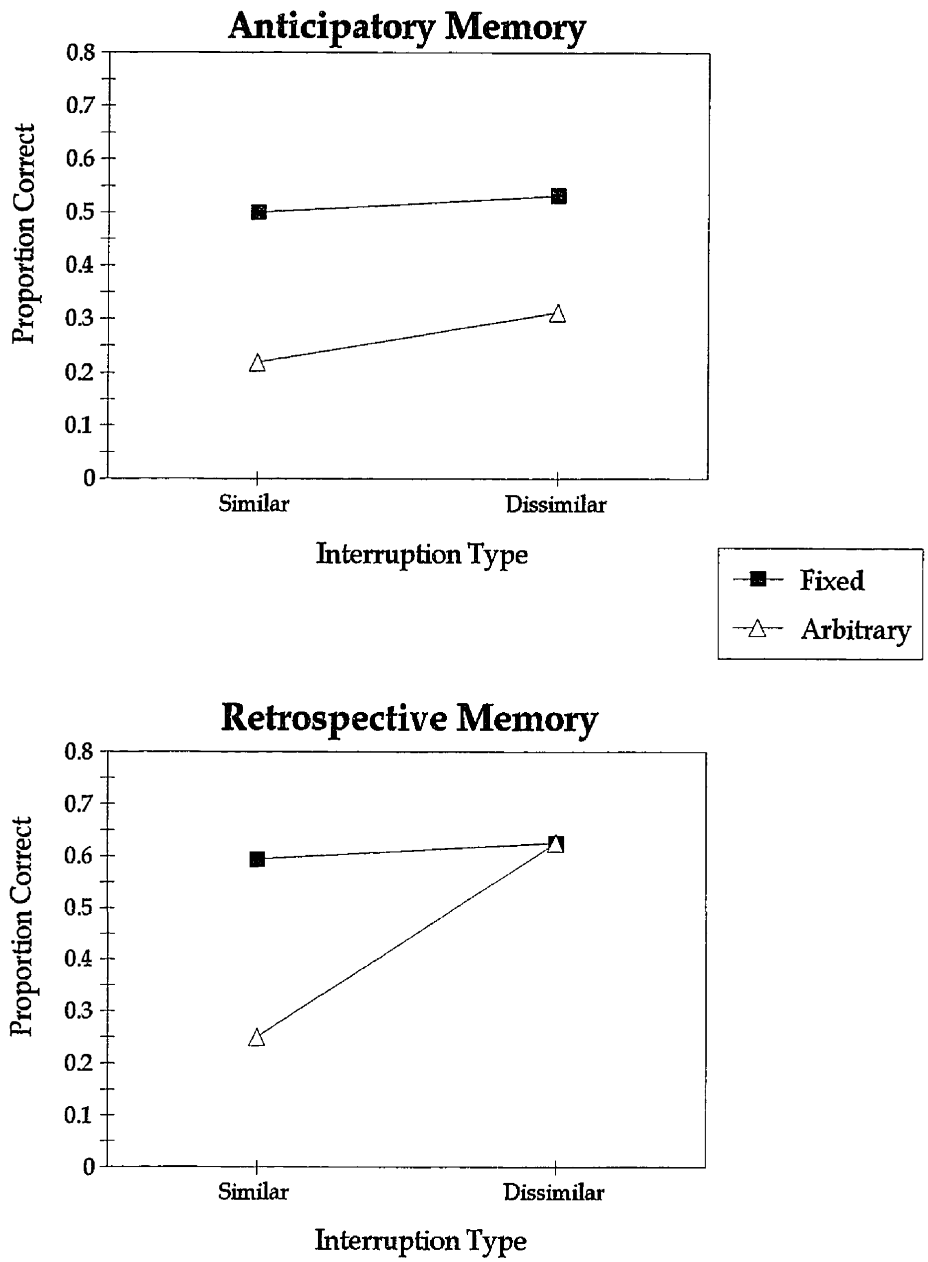

Anticipatory Memory
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion Correct
Similar
Dissimilar
Interruption Type
Fixed
Arbitrary
Retrospective Memory
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion Correct
Similar
Dissimilar
Interruption Type

Figure 4

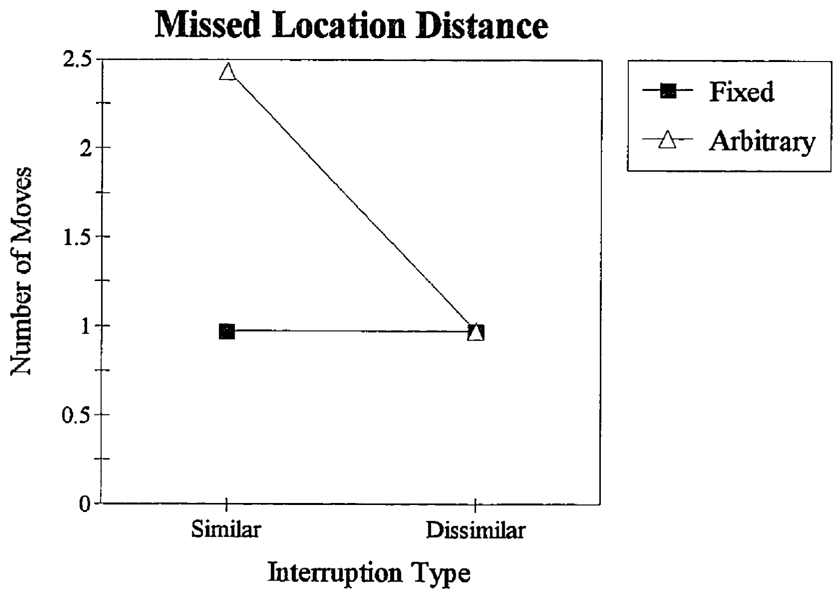

Missed Location Distance
2.5
2
1.5
1
0.5
0
Number of Moves
Similar
Dissimilar
Interruption Type
Fixed
Arbitrary

Figure 5

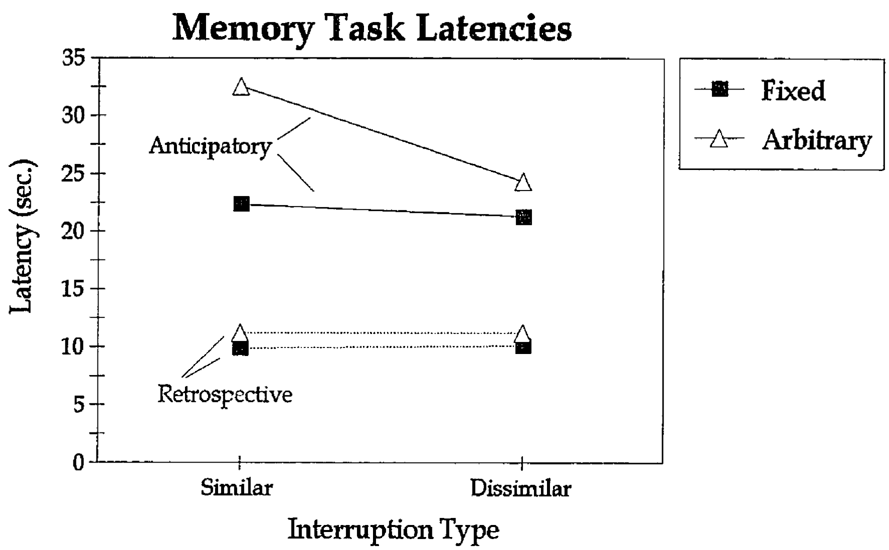
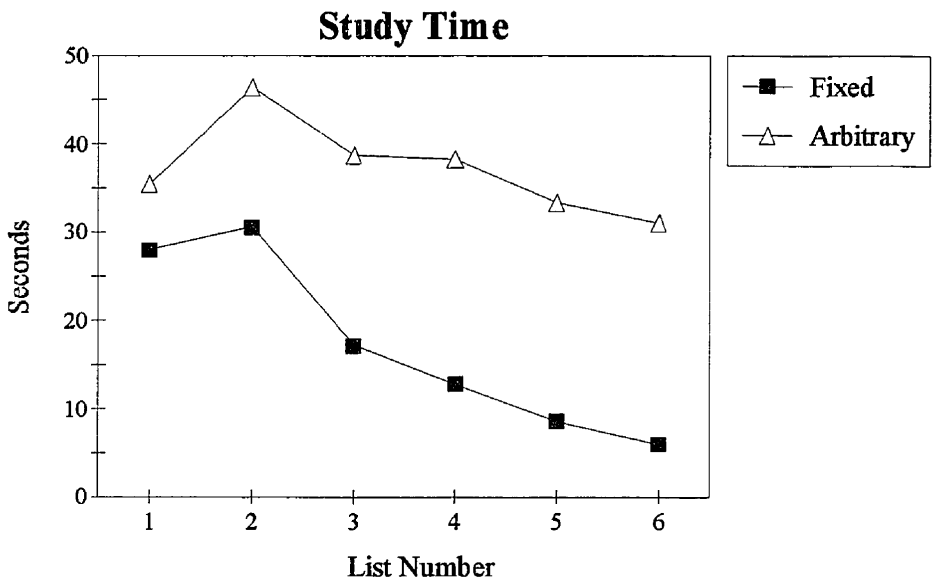

Memory Task Latencies
35
30
25
20
15
10
5
0
Latency (sec.)
Anticipatory
Retrospective
Similar
Dissimilar
Interruption Type
Fixed
Arbitrary

Figure 6



Study Time
50
40
30
20
10
0
Seconds
1
2
3
4
5
6
List Number
Fixed
Arbitrary

Figure 7

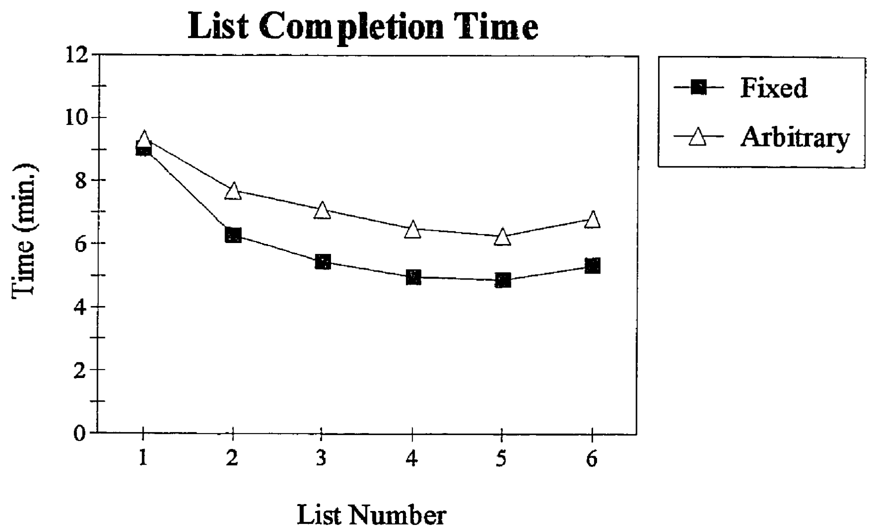

List Completion Time
12
10
8
6
4
2
0
Time (min.)
1
2
3
4
5
6
List Number
Fixed
Arbitrary

Figure 8

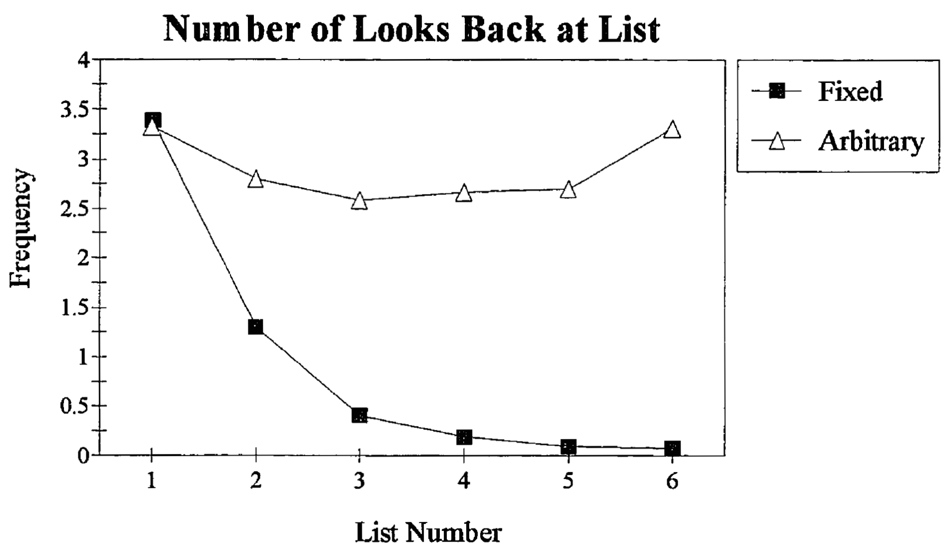

Number of Looks Back at List
Frequency
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
List Number
Fixed
Arbitrary

Figure 9

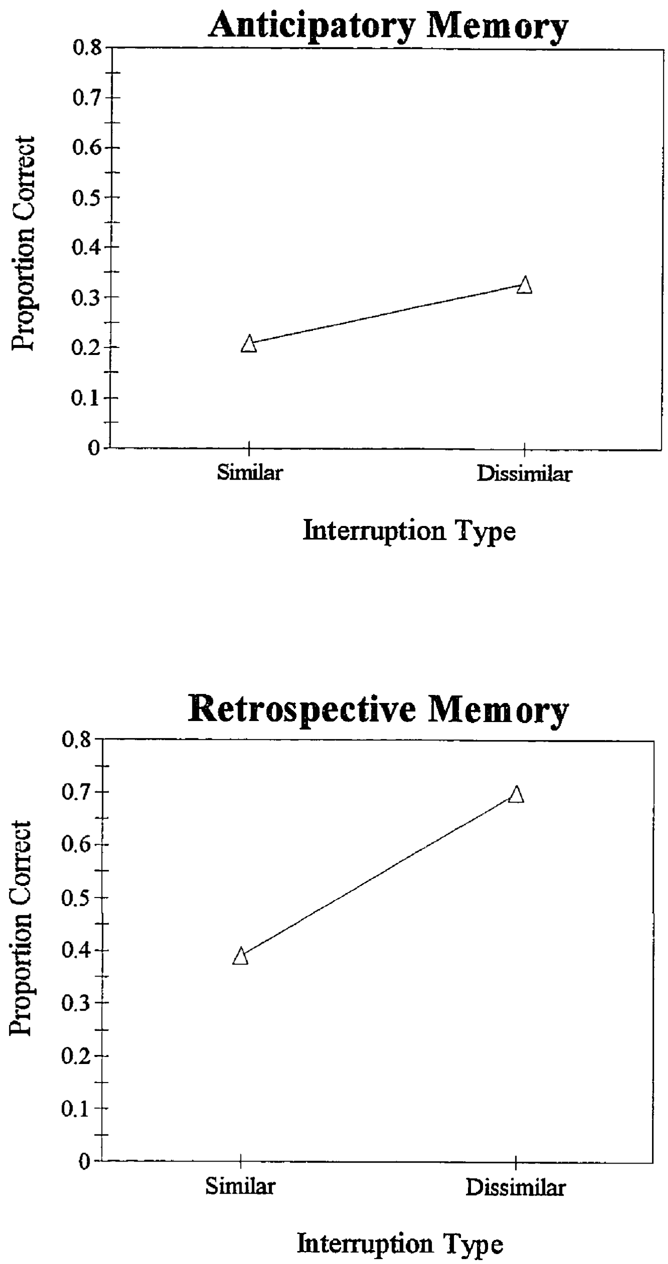

Anticipatory Memory
Proportion Correct
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Similar
Dissimilar
Interruption Type
Retrospective Memory
Proportion Correct
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Similar
Dissimilar
Interruption Type

Figure 10

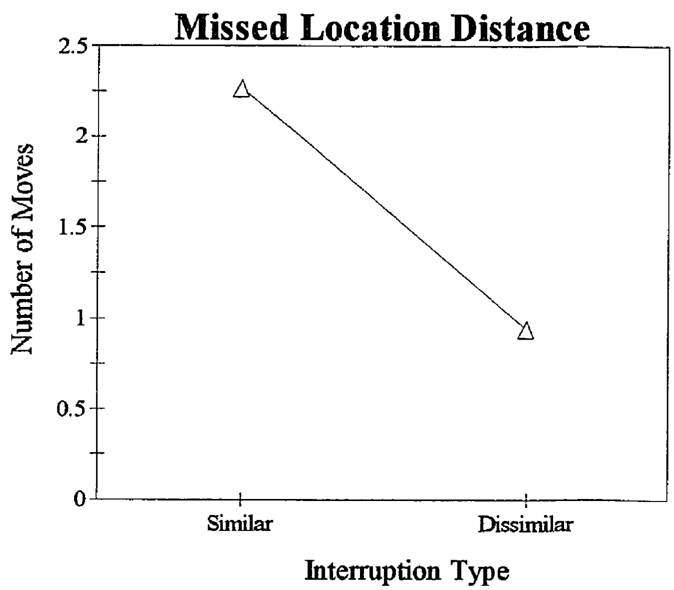

Missed Location Distance
2.5
2
1.5
1
0.5
0
Number of Moves
Similar
Dissimilar
Interruption Type

Figure 11

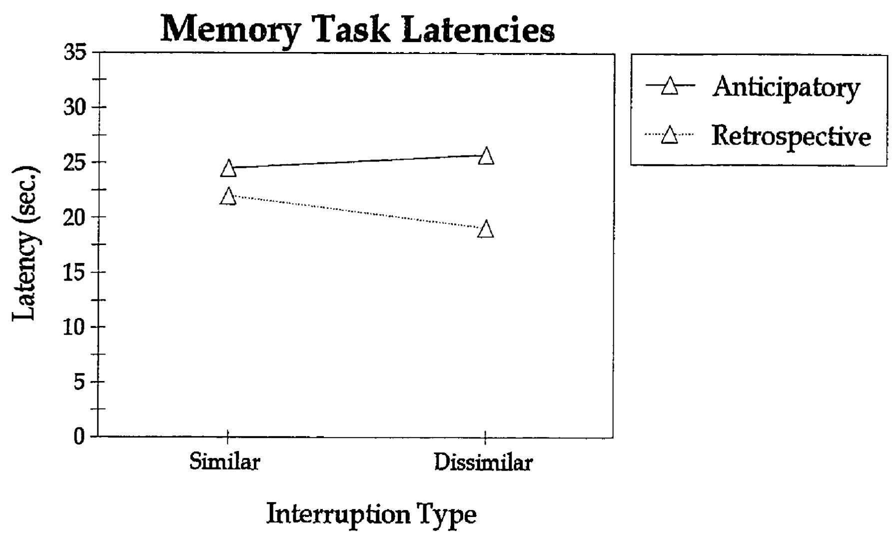

Memory Task Latencies
Latency (sec.)
35
30
25
20
15
10
5
0
Similar
Dissimilar
Interruption Type
Anticipatory
Retrospective

Figure 12

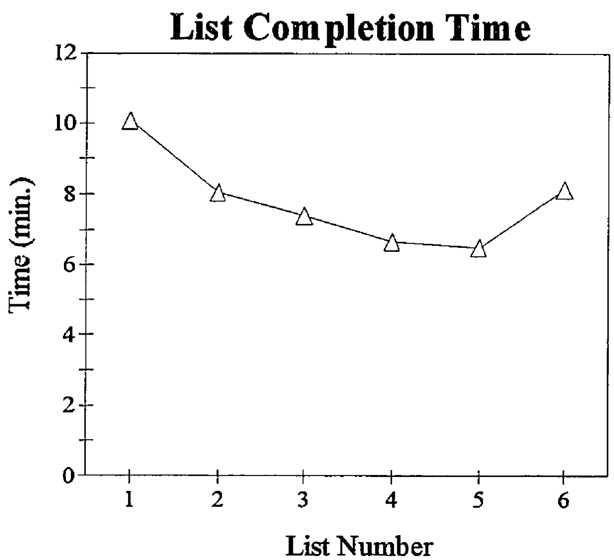
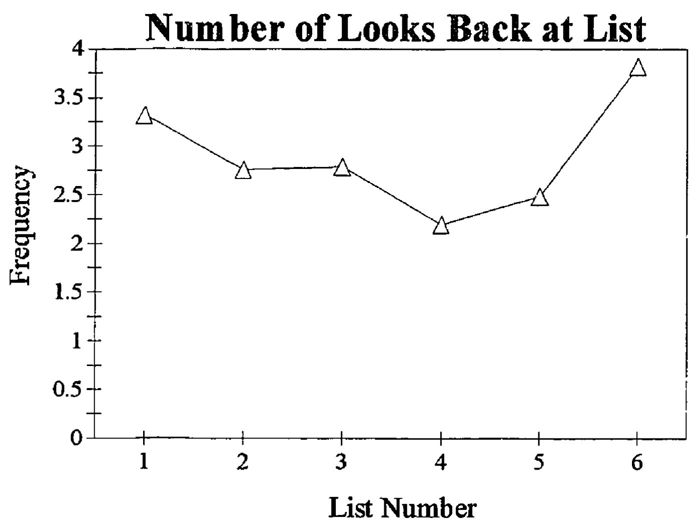

List Completion Time
12
10
8
6
4
2
0
Time (min.)
1
2
3
4
5
6
List Number

Figure 13



Number of Looks Back at List
Frequency
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
List Number