Studies of Alternative Representations:

Selective Interference and Experience

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Dissertation
submitted in partial fulfillment of requirements
for the degree of
Doctor of Philosophy in Psychology
1996

Abstract

(Psychology · Cognitive)

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Abstract

Prior research has established an effect of alternative representations, where individuals who encounter one format of given information outperform individuals who encounter another format of the exact same information. Spatial representations (e.g., tree diagrams, matrices, graphs) generally assist performance relative to textual representations (e.g., paragraphs, lists, outlines). Prior research has involved memory, problem-solving, decision-making, categorization and other cognitive tasks.

Variables manipulated in the current research comprising seven experiments were representational format, content and format of an intervening task, and level of participant experience. An initial experiment demonstrated baseline performance for cued recall across four alternative representations of medication side-effects information, against which performance in subsequent experiments was compared. Memory for information contained in spatial representations was consistently more accurate than memory for identical information contained in textual representations. Two experiments did not succeed in selectively interfering with accuracy levels using matching filler tasks, but in two other experiments it was possible to affect accuracy using experienced participants.

A model is presented to describe how individuals process information from alternative representations. A final experiment supported the hypothesis that alternative representations differently emphasize dimensions which underlie this side-effects information. Conclusions and implications for the current and future research are discussed.

Acknowledgements

I wish to thank the members of my committee for lending guidance and support to my studies. I am particularly grateful to Ruth Day, who has provided direction and assistance in nearly every phase of my advancement in the profession of cognitive psychology. My fellow psychology graduate students at Duke are insightful, supportive, helpful, interested, intelligent, and downright enjoyable people. I have been fortunate to share with Boyce Byerly an office, research interests, numerous paper drafts, and three years of friendship. I of course honor my parents, family and friends who followed me through this endeavor. My wife, Elaine, has marched right with me through every stage of graduate (and undergraduate) school. My gratitude for her help and encouragement cannot be expressed adequately on this page.

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Chapter 1. Introduction

Everyday situations demand that we understand and remember information. We follow signs, read instructions, and interpret signals and symbols. When we drive a vehicle through construction, use a new appliance, attend a lecture, or read professional journals, we are presented with important information. It is of particular interest to cognitive psychologists to understand how we process given information, to know what enables us to remember information on a sheet of paper, or chalkboard, or computer screen.

Preview

A frequently-used term for information that is explicitly presented is ***external representation***. Representation is a catch-all word in cognitive psychology; information gets represented. Interesting research questions ask what information is involved and how it gets represented. The research presented here focuses on memory for a common source of important information, medication side-effects information. The information was presented in four alternative formats. Effects of these alternative formats, called ***alternative representations***, on memory for side-effects information were investigated.

Two other variables were manipulated as well, type of filler task and experience level of individuals who studied the information. The filler task was interposed between the study of side-effects information and test of memory for that information. Type of filler task was altered to investigate selective interference of side-effects information; that is, tasks were designed in an attempt to adversely affect memory test performance for those who encountered matching study and filler formats, but not for those whose study and filler formats mis-matched. Selective interference was viewed as a means to understanding how individuals process the given side-effects information.

Level of experience with side-effects information was also viewed as a means of understanding processing of information. Prior experience with a body of knowledge enables one to incorporate new knowledge into an existing knowledge structure. Subjects having differing levels of experience with medication information were recruited to participate in the current research to investigate whether or not level of experience interacted with type of representation of information.

This thesis is organized into five remaining chapters. Chapter 2 provides background on external and alternative representations, then presents Experiments 2-1 & 2-2, which established baseline results, against which results from subsequent experiments were compared. Chapter 3 discusses interference literature that suggests why selective interference might occur, then presents Experiments 3-1 & 3-2, which varied the filler task. Chapter 4 discusses expertise literature that suggests why level of experience might affect information processing, then presents Experiments 4-1 & 4-2, which replicated Experiments 2-1 & 3-2, respectively, using experienced subjects. Chapter 5 makes sense of results by proposing a model of processing of external information, then presents Experiment 5-1, which altered study representations to test the model. Chapter 6 summarizes the entire line of research, draws some conclusions, and provides implications.

Notes on Experimental Procedure

Standard Paradigm

All experiments described in the current research followed a standard procedure. Briefly, subjects studied medication side-effects information for three minutes, performed a filler task for three minutes, then attempted to recall the side-effects information they had previously studied. The procedure is described in full below, during description of Experiment 2-1; modifications to standard procedure are noted in descriptions of subsequent experiments. As described above, such modifications include use of alternative filler tasks and subjects with varying levels of medication side-effects experience. Table 1-1 highlights in italics major differences between Experiments 2-2 through 5-1 and the baseline Experiment 2-1.

Since Experiment 2-1 was run to establish baseline results, data from subjects participating in that experiment are reused in comparative analyses of subsequent experiments.

Description of Study Information

Study information was kept constant throughout all experiments. All experiments dealt with potential side-effects for a fictitious prescription drug called "Drug X". For 24 side-effects, information on both severity and frequency of occurrence was given: Four levels for severity ("report to doctor

Table 1-1

Overview of Experiments

#	Description	Purpose	Study Reps.	Filler Task	Subjects
2-1	Baseline	establish baseline results	P,O,T,M†	general medication questions	novice undergraduates
2-2a	Control I	rule out potential confound	***T,M modified***	general medication questions	novice undergraduates
2-2b	Control II	rule out effects of uninteresting variables	P,O,T,M	general medication questions	novice undergraduates
3-1	Interference I	test selective interference	P,O,T,M	***math parse trees, progressive matrices***	novice undergraduates
3-2	Interference II	controlled test of selective interference	P,O,T,M	***nutrition information questions‡***	novice undergraduates
4-1	Experience I	test role of experience	P,O,T,M	general medication questions	***pharmacy, medical students***
4-2	Experience II	test role of experience and selective interference	P,O,T,M	***nutrition information questions***	***pharmacy, medical students***
5-1	Transposition	test process model predictions	***P,T,M transposed***	general medication questions	novice undergraduates

† P - Paragraph, O - Outline, T - Tree, M - Matrix

‡ alternative representations in same four (P,O,T,M) formats

immediately", "report to doctor", "may go away during treatment", and "usually requires no medical attention"); three levels for frequency ("more common", "less common", and "rare").[1] Thus, there were two side-effects in each severity by

1. Concurrent research by Day and Hubal has shown that these severity terms, which describe actions to take, are seen by both Duke undergraduate and University of North Carolina pharmacy school students to correspond with descriptive severity terms, such as "life-threatening", "dangerous", and "troublesome". Similarly, these frequency terms have been measured in meaning against other frequency terms. (See also Budescu & Wallsten, 1985;

frequency cell. Byerly (1996) describes in detail how assignments of side-effects to severity and frequency levels compare with severity and frequency ratings by expert pharmacologists. In addition, four side-effects were given no severity or frequency information. This manipulation was realistic, since side-effects information provided for a prescription drug often states "Side-effects include…" but provides no severity or frequency information (Day, 1995).

Further Constants across Experiments

Several other aspects of methodology, in addition to the study information, were kept constant across experiments. For instance, a cued recall memory task was used throughout; subjects were asked to recall severity and frequency information for all 28 side-effects. Similarly, study time, filler time, and inter-item test interval remained constant throughout all experiments. These times were tested with pilot Duke undergraduate subjects to demonstrate robust memory performance differences across representations. Finally, accuracy, defined as percent correct responses across all 28 side-effects on the memory test, served as the dependent variable for all experiments. A combined accuracy score for both severity and frequency information is generally reported, except when severity and frequency yielded different patterns of results. Exact significance values are reported for all statistical tests.

Levels of Experience Included

Two levels of pharmaceutical expertise (i.e., experience with side-effects information) were included here: Novice Duke undergraduate students, and

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Sutherland et al., 1991.) Actual terms used, therefore, were not as important as the varying levels of severity or frequency that they implied.

intermediate University of North Carolina pharmacy and Duke medical students. While many investigations have demonstrated superior performance by experts over novices (for reviews, see Chi, Farr, & Glaser, 1988; Ericsson & Smith, 1991), some have demonstrated that performance does not necessarily increase along with experience (e.g., Bettman & Park, 1980; Cooke & Schvaneveldt, 1988; Myles-Worsley, Johnston, & Simons, 1988; Patel & Groen, 1991). Unhappily, without expert pharmacists and doctors, monotonic increase in performance across levels of experience could not be tested. However, some expertise investigations have demonstrated that type of expertise affects performance (e.g., McGraw & Pinney, 1990; Patel & Groen, 1991; Smith, 1990; Weiser & Shertz 1983). Type of expertise was tested by comparing pharmacy and medical students. These issues are addressed in Chapter 4.

Chapter 2. Representation

This chapter discusses external and alternative representations in detail, then describes Experiments 2-1 & 2-2. Experiment 2-1 replicated the effect of alternative representations on memory performance in a new content domain, and established baseline performance against which results of Experiments 3-1 through 5-1 may be compared. Experiment 2-2 replicated baseline results using controlled materials to discredit confounding explanations.

External Representation

This section defines representation and the formats that representations can take, then surveys the representation literature.

Definitions and Types of Representation

"A representation is something that stands for something else…it is a kind of a model of the thing it represents" (Rumelhart & Norman, 1986, p. 513). Representations "depict", "portray", "delineate" or "picture" (Webster's, 1986, p. 1926), synonyms that suggest the variety of linguistic, graphic, linear, and pictorial representations of information. A representation makes real-world knowledge (objects, events, situations) accessible and modifiable. Typically, representations are considered either "internal" or "external".[2] Both types of representation can vary in amount or kind of information (e.g., sentences vs. diagrams, Larkin & Simon, 1987) provided. Both types of representation can take various configural forms; any two representations that possess virtually the same information in different form are called "alternative representations" (Day, 1988) or "isomorphic representations" (Ichikawa, 1989). Internal and external representations differ mainly in how, for a given subject, an investigator must access them. If the investigator's own physical senses directly interact with representations then they are external. If the investigator requires indirect techniques (e.g., categorization tasks) to access representations then they are internal to the subject.

Forms of Representation

Investigators have examined numerous external representational formats in numerous content domains, as illustrated in Table 2-1. Investigations of internal representational form normally concentrate on cognitive knowledge structure, literally the structure of mental information (Cooke & Schvaneveldt, 1988; Freyhof, Gruber, & Ziegler, 1992; Murphy & Wright, 1984; Rumelhart & Norman, 1986; Schvaneveldt et al., 1985). Hassebrock et al. (1993; see also Olson & Biolsi, 1991) distinguish two approaches which reveal internal knowledge representation, sorting tasks (e.g., Chi, Feltovich, & Glaser, 1981; Garland & Barry, 1991-92; Schoenfeld & Herrmann, 1982) and memory tasks (e.g., Chase & Simon, 1973; Chiesi,

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2. Internal representation is also called "mental representation" (Simon, 1989) or "cognitive representation" (Anzai, 1991). External representation is also called "problem representation" (McGuinness, 1986) or "symbolic representation" (Novick & Hmelo, 1994).

Table 2-1
Forms of External Representation

Representation	Content Domain	Reference
diagrams	'design' problem-solving	Carroll, Thomas, & Malhotra (1980)
	electronic circuit drawings	Egan & Schwartz (1979)
	checkerboard & analogies	Gick & McGarry (1992)
	Bayesian probabilities	Ichikawa (1989)
	nutrition labels	Levy, Fein, & Schucker (1992)
	process control simulation	Vicente (1992)
graphs	line graphs	Shah & Carpenter (1995)
	energy labels	Verplanken & Weenig (1993)
lists	medication instructions	Day (1988)
	unit price information	Russo, Krieser, & Miyashita (1975)
	nutrition information	Russo et al. (1986)
matrices	breakfast cereal choices	Bettman & Kakkar (1977)
	medication instructions	Day (1988)
	deductive reasoning problems	Polich & Schwartz (1974)
	loan applications	Schkade & Kleinmuntz (1994)
perceptual symbols	bus schedules	Day (1988)
	nutrition labels	Levy et al. (1992)
	alphabetic characters	Lockhead & Crist (1980)
pictures	Tower-of-Hanoi analogies	Kotovsky, Hayes, & Simon (1985)
	Tower-of-Hanoi problem	Zhang & Norman (1994)
tree diagrams	lecture notes	Day (1980)
	family relationships	McGuinness (1986)
	deductive reasoning problems	Polich & Schwartz (1974)
words	dance sequences	Day & Kee (1994)
	mechanics, geometry problems	Larkin & Simon (1987)
	nutrition labels	Levy et al. (1992)

Spilich, & Voss, 1979); similarity scaling tasks (e.g., Cooke & Schvaneveldt, 1988) represent a third approach. Since internal representation relates closely to knowledge structure, it bears on a vast literature. Examples in which internal representational form plays an important role include dual coding in imagery (Paivio, 1983), natural categories (Rosch, 1973), script or schema theory (Schank & Abelson, 1977), and network (e.g., Rumelhart & McClelland, 1986) versus rule-based (e.g., Anderson, 1983; Fodor & Pylyshyn, 1988) cognitive architectures.

Although internal representation is more widely studied, Day (1988, p. 262) provides a rationale for studying external representations:

> No claim is made for a one-to-one correspondence between the external representation provided and subjects' internal representation. However, if we obtain systematic, robust performance differences across alternative representations, we can conclude that the internal representation is more similar to the format subjects studied than to other possible representations. Then we can study how specific properties of each representation affect performance in various cognitive tasks.

Furthermore, since an investigator cannot directly observe internal representations, and since subjects' verbal reports about them must be used cautiously (see Ericsson & Simon, 1993), external representations and their effects on cognitive task performance are a sound way to study internal representations.

Standard Findings

External Representations Assist Performance. Generally, an external representation assists in performance of a task. Memory studies (bus schedules, Day, 1988; Mayer, 1976; Norman, 1993; Wollen, Weber, & Lowry, 1972) and problem-solving studies (Bettman & Kakkar, 1977; Carroll, Thomas, & Malhotra, 1980; medication instructions, Day, 1988; Gick, 1985; Kotovsky, Hayes, & Simon, 1985, experiment 4a; Novick & Hmelo, 1994; Polich & Schwartz, 1974; Russo, Krieser, & Miyashita, 1975; Schwartz, 1971; Schwartz & Fattaleh, 1972; Simon &

Hayes, 1976; Vicente, 1992; but see Dee-Lucas & Larkin, 1991; Gick & Holyoak, 1983, experiment 3) consistently support this finding. For instance, Gick (1985), on an analogical transfer task, either did or did not present a source problem's diagram along with the target problem. Gick found inclusion of this diagram to be an effective retrieval cue for the source solution procedure. Similarly, Kotovsky et al. (1985, experiment 4a), on a Tower of Hanoi problem isomorph, either did or did not present a clarifying picture. Inclusion of the picture enabled significantly faster solution times.

Analogous Internal Representations Assist Performance. Internal representations can act like external representations during some tasks (Anzai, 1991; Bower & Morrow, 1990; Gott, Bennett, & Gillet, 1986; Hanisch, Kramer, & Hulin, 1991; Hatano & Osawa, 1983; Kieras & Bovair, 1984; McNamara, 1991; Miller & Stigler, 1991; see also Olson & Biolsi, 1991, pp. 271-278). For instance, Hatano and Osawa (1983) found mental abacus calculation experts to represent digits in an abacus image. Similarly, Bower and Morrow (1990) describe how, during narrative comprehension, readers construct mental pictures from narrative details. Keren (1984), on a probability problem, demonstrated the importance of the internal "representation of the task environment that permits the consideration of different problem situations and sets limitations on possible operations that can be applied" (p. 122). Twice as many subjects derived the correct solution with an internal tree diagram as with an internal list representation. A large body of research focuses on visual imagery, and how individuals represent object sizes (see Kosslyn, 1975), shapes (Shepard & Chipman, 1970) and rotation (Shepard & Metzler, 1971). This effect of internal images which act like external representations to assist performance will resurface below.

Spontaneous Use of External Representations. Investigations differ as to who prepares the representation, investigators (Bettman & Kakkar, 1977; Day, 1988; Egan & Schwartz, 1979; Gick, 1985; Kotovsky et al., 1985; Mayer, 1976; Mayer & Gallini, 1990; McGuiness, 1986; Russo et al., 1975; Schkade & Kleinmuntz, 1994) or subjects (Anzai, 1991; Carroll et al., 1980; Novick, 1990; Novick & Hmelo, 1994; Polich & Schwartz, 1974; Schwartz, 1971; Schwartz & Fattaleh, 1972; Simon & Hayes, 1976). When investigators prepare the external representation, they are testing how well subjects can do with specific materials. Such is the method used in the current research.

When subjects prepare the external representation, investigators are testing how well subjects actually do with their own materials (Day, 1988; Stein & Bransford, 1979). Individuals will not always generate, or consistently use, an external representation (Carroll et al., 1980; Polich & Schwartz, 1974; Schwartz, 1971; Schwartz & Fattaleh, 1972; Simon & Hayes, 1976), even though a representation might assist cognitive task performance. For instance, Carroll et al. (1980) presented either a spatial design problem or an isomorphic temporal design problem. Most individuals in the spatial condition created a matrix, whereas few in the temporal condition did. However, when given a matrix to use, differences between conditions diminished. Similarly, Schwartz (1971; also Polich & Schwartz, 1974), on "whodunit" problems, was forced to classify a small but reliable percentage of subjects as not using an external representation. Only one-quarter of such subjects solved problems, whereas one-half to three-quarters of subjects who created representations (and consistently used them) succeeded. When individuals do generate an external representation it does not always prove most helpful (Kaiser, Jonides, & Alexander, 1986; McCloskey, Caramazza, & Green, 1980; Polich & Schwartz, 1974; Schwartz, 1971; but see Novick &

Hmelo, 1994; Schwartz & Fattaleh, 1972). For instance, of the subjects in Schwartz (1971) who created representations, matrix users significantly outperformed alternative representation (tree structure, words) users.

In sum, the representation literature encompasses investigations involving numerous forms of representation. When provided by an investigator, or when imagined by subjects, a representation generally assists performance. However, different provided representations, and different representations generated by subjects, have differing effects on performance. The alternative representations literature addresses these differences.

Alternative Representations

Investigations sometimes study effects of a single representation (Egan & Schwartz, 1979; Gick, 1985; Kotovsky et al., 1985; Novick, 1990), but often alternative representations, as illustrated in Table 2-2. Prior alternative representations research has demonstrated that when identical information is displayed using alternative formats, resulting cognitive task performance differs. Generally, spatial representations assist performance more than non-spatial alternatives. Day and colleagues (e.g., Allen, 1995; Breitner, 1996; Day, 1988; McKay, 1993) consistently find such results using matrix and tree diagrams, compared to lists and outlines, on numerous tasks, from a recall task by children of household items to memory and comprehension of medication instructions. Many other researchers (e.g., Carroll et al., 1980;

Table 2-2

Studies using Alternative Representations

Alternative Representations	Reference
lists, matrix	Bettman & Kakkar (1977)
iconic display, bar graph	Carswell & Wickens (1987)
list, matrix	Day (1988)
equations, sentences	Dee-Lucas & Larkin (1991)
equations, diagrams	Ichikawa (1989)
lists, diagrams	Larkin & Simon (1987)
phrases, numbers, bar graphs	Levy, Fein, & Schucker (1992)
static, dynamic illustrations	Mayer & Gallini (1990)
trees, matrices	McGuinness (1986)
tree, network, matrix	Novick & Hmelo (1994)
lists, matrix; phrases, numbers	Schkade & Kleinmuntz (1994)
matrix, sentence, network	Schwartz & Fattaleh (1972)
sentences, drawings	Tymchuk et al. (1988)

Ichikawa, 1989; Larkin & Simon, 1987; Mayer, 1976; Schwartz, 1971; Tymchuk, Ouslander, & Rader, 1986) obtain similar results.

Alternative representations, while portraying the same information, do so in different configural forms, and therefore differ in applicability to specific cognitive tasks (cf. Zhang & Norman, 1994). For instance, Levy, Fein, and Schucker (1992) discovered individuals prefer nutrition labels containing adjectives or bar graphs, but perform better on a comparison task when labels list only numeric values. Similarly, Larkin and Simon (1987) demonstrated that diagrams exceed list-like representations in computational efficiency on search and recognition tasks, but not on inference tasks. Also, Zhang (1996) contrasts graphic and tabular relational information displays, demonstrating how the different displays are used during information retrieval (i.e., search), comparison, and integration tasks. Additionally, McGuiness (1986) showed that matrices and tree structures serve different uses on different tasks in representing family relationships. Alternative representations also affect acquisition of information (Bettman & Kakkar, 1977; Barnes & Whitely, 1981; Larkin & Simon, 1987; Zeitz & Spoehr, 1989), a point addressed while discussing a model of information processing in Chapters 3 & 5.

In sum, representation affects cognitive task performance. The current research mostly concerns how alternative external representations affect performance on a memory task. Generally, an external representation assists, but alternative representations vary in assistance. These general findings are explored in detail in these experiments by manipulating representational format, filler tasks, and level of experience of participating subjects.

Experiment 2-1 · Baseline

Experiment 2-1 tested four alternative representations of medication side-effects information. The four representations, Paragraph, Outline, Tree, and Matrix, were reused throughout the current research, but with different filler tasks and/or participating subjects. A baseline of novice performance, then, was needed, against which results from Experiments 2-2 through 5-1 could be compared. Experiment 2-1 provided baseline results.

Undergraduate students served as novice subjects for the following reason: They were not completely naive in their knowledge about side-effects (e.g., severity, frequency of occurrence, body area affected, duration), nor were they near to being expert. The experience of doctors, pharmacists, and nurses leads to considerable knowledge regarding side-effects, whereas the experience of undergraduates leads to knowledge about the meaning of side-effects terms and body area affected, but little else (see Byerly, 1996, for a description of knowledge structures that novices bring into these experiments).

Two representations used, Paragraph and Outline, are textual; both basically involve sentential representation of information. The two others, Tree and Matrix, are spatial, representing information by using spatial cues. As described above, prior external representation research often demonstrates better performance when subjects use spatial formats rather than textual formats. Similar results, even though subjects had considerably more experience studying paragraphs and outlines than studying tree diagrams and matrices, were anticipated for this baseline experiment.

Method

Subjects. Experiment 2-1 used Duke University undergraduate students who received course credit as part of the introductory psychology subject pool. A total of 46 subjects participated. Subjects were run individually or in small group sessions. Details of number of participants per condition are given in a table below.

Materials. Every subject was handed a booklet of four pages. A colored title page hid the study page from view. A study page contained side-effects information. A filler task and a response sheet for the memory test were both completed by all subjects. The final three pages are described in turn.

Study Representation. The study page contained side-effects information for Drug X in one of four alternative formats, Paragraph, Outline, Tree, or

Matrix. Each subject studied only one representation.

The Paragraph representation (Figure A-1) stated side-effects information in sentential form. Its first sentence listed four side-effects but provided no severity or frequency information. Each of four subsequent sentences stated a description of severity, three descriptions of frequency, and two specific side-effects for each frequency term under that severity term. The Outline representation (Figure A-2) formed an outline from these sentences without rearranging their order. Thus, severity information formed four major outline sections, frequency information formed three minor sections within each, and two side-effects were listed for each frequency term under each severity term.

The Tree representation (Figure A-3) had four branches descending from its root "Drug X", each branch representing a level of severity. Beneath each branch three nodes indicated three levels of frequency. Each of the 12 resulting nodes listed two side-effects. A single detached node near the bottom of the page listed four side-effects for which no severity or frequency information was given.

The Matrix representation (Figure A-4) had four levels of severity along its left, vertical axis, and three levels of frequency along its top, horizontal axis. Each of the 12 resulting cells listed two side-effects. An additional thirteenth cell, marked by two question marks indicating no information for either severity or frequency, listed four side-effects.[3]

<u>Filler</u> <u>Task</u>. The filler task (Figure B-1) prevented subjects from rehearsing study information and allowed forgetting to occur. It required subjects to answer general side-effects questions not directly related to the study

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3. Study representation materials were carefully designed. Special features, such as capitalization and italicization in the Paragraph and line width in the Tree, represented additional sources of information for subjects.

information.

Response Sheet. A box near the top of the response sheet (see Figure C-1) listed valid severity values, pairing a number from 1 through 4 with each valid value. An adjacent box listed valid frequency values, pairing a number from 1 through 3 with each valid value. Thus, numbers identified specific levels within each dimension. Also in each box, 0 was paired with a value indicating no information given. The response sheet was numbered from 1 to 28 (the number of side-effects studied), each having two blanks. The first blank was used by subjects to enter a severity response, the second to enter a frequency response. Subjects completed both blanks by entering a single number ranging from 0 through 4 for severity and a single number ranging from 0 through 3 for frequency.

Procedure. All experiments followed the basic procedures in this baseline Experiment 2-1. Subjects were given a booklet with its title page showing. They were told this would be an experiment on side-effects of one particular prescription drug, Drug X, that they should envision themselves as patients taking Drug X, and that they should study the following page of information so that they understood it. Subjects were given three minutes to study, and were not allowed to turn forward or backward in the booklet during this time. Furthermore, subjects were not allowed to write on the study page, so that they could not overtly change the form of representation. After three minutes, subjects turned to the next page, the filler task, and completed questions or problems presented there. Subjects were told to answer all questions, even if they had to guess. Subjects were given three minutes for the filler task. Again, they were not allowed to turn forward or backward in the booklet during this time. After three minutes, subjects turned to the response sheet. They were instructed to write down two responses for each item (i.e., side-effect) to be read to them, a number between 0 and 4 for severity, and a number between 0 and 3 for frequency. Items were read aloud with a five second inter-item interval. The memory test concluded each experiment.

Results and Discussion

Figure 2-1 plots results of Experiment 2-1; Table 2-3 tabulates results. An analysis of variance demonstrated at least one significant difference among the accuracy means across representations ($F_{3,42}$=17.15, p<.0001).[4] Planned contrasts demonstrated an advantage in memory performance for subjects who received the spatial Tree and Matrix representations over subjects who received the Paragraph and Outline representations ($F_{1,42}$=44.36, p<.0001). No performance difference was found between the two spatial conditions by a t-test, nor between the two non-spatial conditions.[5] Prior research (e.g., Day, 1988; Ichikawa, 1989; Larkin & Simon, 1987) has shown how matrices, trees, graphs or other spatial representations assist performance over textual representations. Experiment 2-1 thus reproduced these results. This pattern, to anticipate, was replicated in all subsequent experiments.

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4. Responses for severity and frequency were combined because they led to equivalent patterns of results: A repeated measures analysis revealed no main effect of response type (severity vs. frequency; $F_{1,42}$=2.85, p<.10) nor an interaction with representation ($F_{3,42}$<1).

5. Bonferroni corrections to all group comparisons controlled the experiment-wise error rate.

Table 2-3
Experiment 2-1 Results
Baseline

Study Rep.	N	Severity Accuracy (%)	Frequency Accuracy (%)	Overall Accuracy (%)	Std. Error (%)
Paragraph	14	46.2	39.8	43.0	2.8
Outline	12	48.0	45.8	46.9	1.9
Tree	10	70.7	67.9	69.3	3.9
Matrix	10	60.7	57.9	59.3	3.0

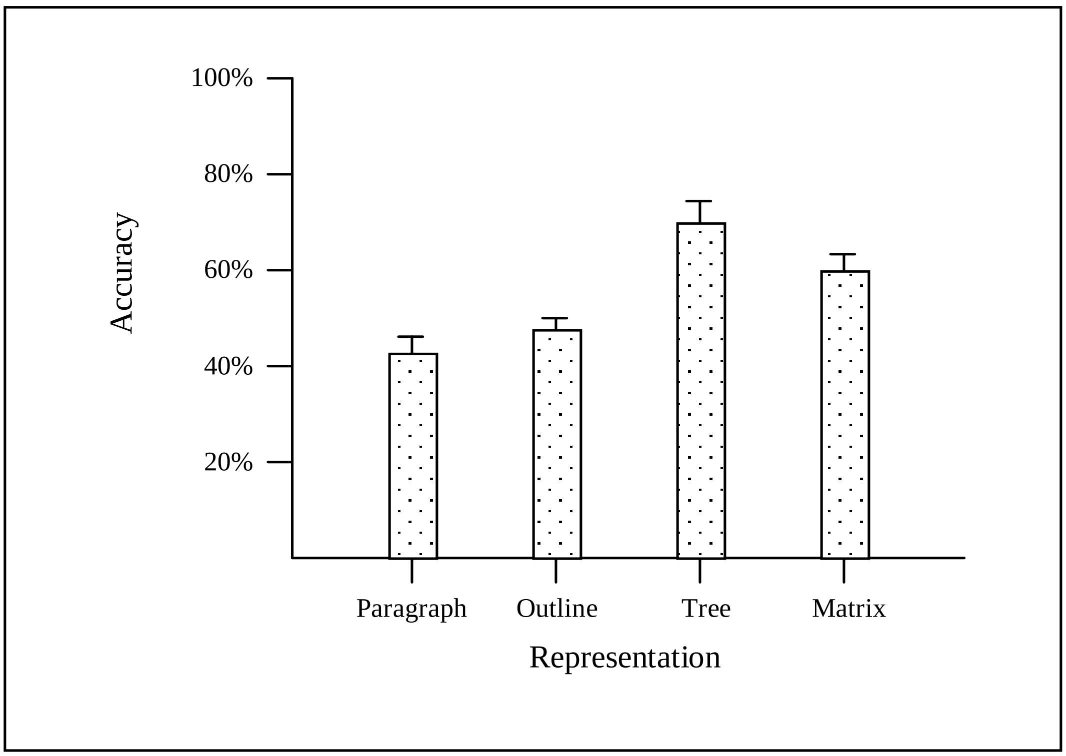

Figure 2-1
Experiment 2-1 Results
Baseline

Experiment 2-2 · Controls

Experiment 2-1 found a pattern among the four alternative representations in which performance in the Paragraph and Outline conditions did not differ, but were both lower than performance in the Tree and Matrix conditions, which also did not differ. Experiment 2-2 was conducted to rule out a potential confound and eliminate "uninteresting" variables from explanation of baseline results.

Experiment 2-2 is split into parts a & b. Experiment 2-2a used modified spatial representations to verify that line thickness in the tree diagram and axis labels on the matrix did not contribute to baseline findings. Experiment 2-2b examined four variables to demonstrate that they need not be considered in explanations for baseline findings. Two of the variables separated subjects either by gender or by compensation (i.e., whether course credit or payment was granted for participation). Two other variables investigated order effects. One variable manipulated was ***item order***, that is, the order in which side-effects were presented during the memory test. Four random orders were devised. All subjects in a given session heard the same item order, but item order was randomly assigned to sessions. Another variable manipulated was ***response order***, that is, how subjects responded during the memory test, with severity information in the first column and frequency in the second, or vice versa. Because none of these four variables are implicated in the explanation of baseline results given below, all four were expected not to affect results.

Method

Subjects. Experiment 2-2a used Duke University undergraduate students.

A total of 40 subjects participated, ten per condition, including (as a baseline) those who participated in the Tree and Matrix conditions of Experiment 2-1.

Experiment 2-2b also used Duke University undergraduate students. Students either received course credit as part of the introductory psychology subject pool, or were paid. A total of 283 subjects participated, including (as a baseline) those who participated in Experiments 2-1 & 2-2a. Data from all subjects were analyzed for potential gender and compensation effects; however data were available from only 85 students to analyze item order and from only 98 students to analyze response order.[6] Details of number of participants per condition are given in tables below.

Materials. Every subject was handed a booklet of four pages. The first page for all subjects was again a colored title page hiding the study page from view. The second through fourth pages contained, respectively, the side-effects information to be studied, a filler task, and a response sheet for the memory test. Differences on these final three pages from the three pages in the baseline experiment are described in turn.

<u>Study</u> <u>Representation</u>. For Experiment 2-2b, the four study representations were exactly those used in Experiment 2-1.

For Experiment 2-2a, two tree diagram and two matrix representations were used. One tree and one matrix were exactly those used in Experiment 2-1. The other tree and matrix representations were slightly modified. Specifically,

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6. Item order was manipulated only for subjects who received the food nutrition filler task described in Chapter 3. There is, though, no reason to believe that filler task and item order would interact, especially with findings described in Chapter 3 showing that filler task and study condition do not interact. Similarly, response order was manipulated only for subjects who received the baseline filler task. There is, though, no reason to believe that filler task and response order would interact, especially with findings described in Chapter 5 showing that it is study condition which predictably affects response accuracy.

in the Modified Tree (Figure A-5) all lines descending from the root "Drug X" had equal width, whereas in the Original Tree width corresponded to level of severity. In the Modified Matrix (Figure A-6), the terms "severity" and "frequency" no longer labelled the vertical and horizontal axes, as they did in the Original Matrix. Beyond these modifications, the modified and original representations were identical.

Filler Task. For Experiment 2-2a the filler task was exactly that used in Experiment 2-1. For those subjects in Experiment 2-2b who were tested on item order, the filler task was the food nutrition task that is described in Experiment 3-2. For all other subjects in Experiment 2-2b, the filler task was exactly that used in Experiment 2-1.

Response Sheet. For Experiment 2-2a the response sheet was exactly that used in Experiment 2-1. For those subjects in Experiment 2-2b who were tested on response order, the response sheet had a single modification (Figure C-2): Subjects entered a frequency response in the first blank of the modified response sheet, whereas they entered a severity response in the first blank of the original response sheet, and vice-versa for the second blank. Subjects still completed both blanks by entering a single number ranging from 0 through 4 for severity and a single number ranging from 0 through 3 for frequency. For all other subjects in Experiment 2-2b, the response sheet was exactly that used in Experiment 2-1.

Procedure. Experiment 2-2 followed the exact same procedures as Experiment 2-1.

Results and Discussion

Figure 2-2 plots results of Experiment 2-2a; Table 2-4 tabulates results. An analysis of variance failed to find any significant effects of study representation (Tree vs. Matrix), type of representation (Original vs. Modified) or their interaction (all $F_{1,36} \leq 2.48$, ***ns.***). Therefore, the baseline results of Experiment 2-1, which showed improved memory performance for subjects in spatial conditions relative to subjects in textual conditions, cannot be explained by thickness of lines in the Tree or presence of axis labels in the Matrix.

Experiment 2-2b examined several other variables which might have unexpectedly affected baseline results. All of these variables were found to be non-significant. For instance, payment versus credit given to subjects did not affect memory performance, neither as a main effect ($F_{1,275}<1$; see Table 2-5) nor in an interaction with representation ($F_{3,275}<1$). Paid and credited subjects were therefore pooled in all subsequent analyses. Similarly, gender did not affect memory performance, neither as a main effect ($F_{1,275}=1$; see Table 2-6) nor in an interaction with representation ($F_{3,275}<1$). This finding conflicts with some prior research (e.g., Halpern, 1989) but supports other research (e.g., Feingold, 1988) regarding gender differences in spatial processing. At least with these representations and this study information, both genders remembered spatial information better than textual information.

Table 2-4
Experiment 2-2a Results
Modified Spatial Representations

Study Representation	N	Overall Accuracy (%)	Std. Error (%)
Original Tree	10	69.3	3.9
Modified Tree	10	63.2	4.5
Original Matrix	10	59.3	3.0
Modified Matrix	10	62.3	4.8

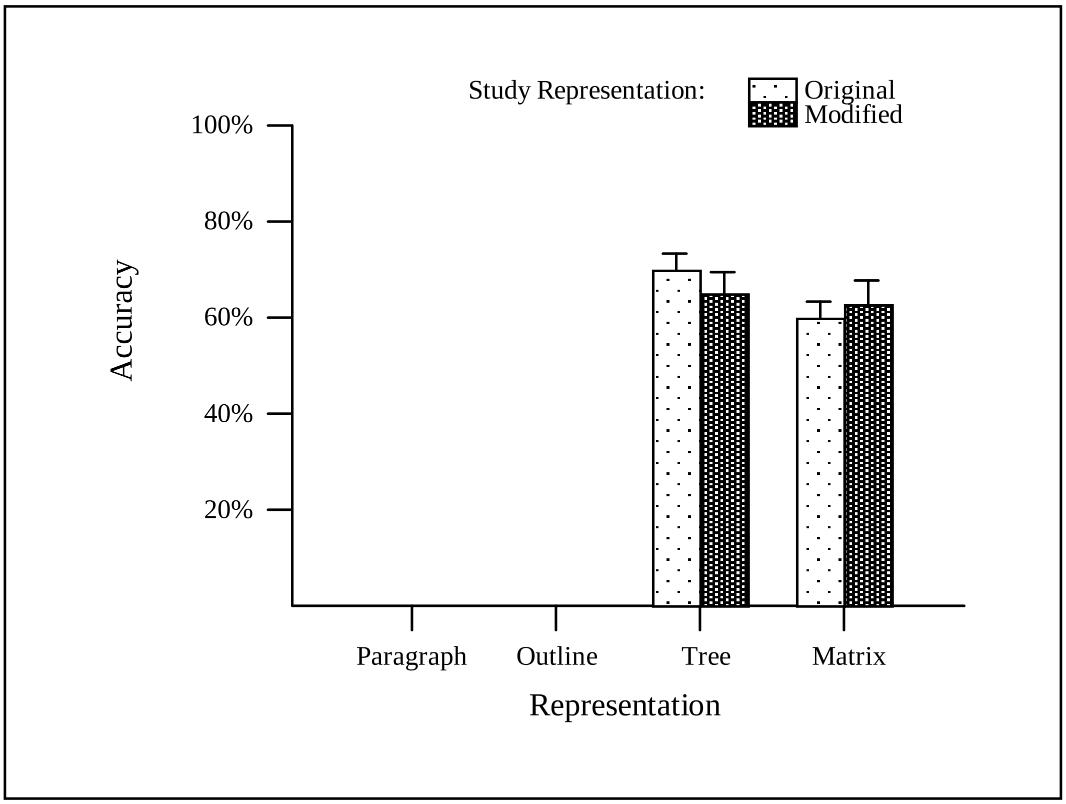

Figure 2-2
Experiment 2-2a Results
Modified Spatial Representations

Table 2-5
Experiment 2-2b Results
Compensation Analysis

Compensation	N	Overall Accuracy (%)	Std. Error (%)
Payment	107	54.0	1.4
Course credit	176	56.5	1.1

Table 2-6
Experiment 2-2b Results
Gender Analysis

Gender	N	Overall Accuracy (%)	Std. Error (%)
Male	116	56.7	1.4
Female	167	54.8	1.1

The order in which items were presented during the memory test (i.e., item order) did not affect results ($F_{3,81}$<1; see Table 2-7); accuracy was equivalent across all four random orders. Similarly, the order in which subjects responded during the memory test (i.e., response order) did not affect results ($F_{1,90}$<1; see Table 2-8); whether subjects were instructed to respond with severity and then frequency information, or frequency and then severity information, memory performance was unaffected.

Table 2-7
Experiment 2-2b Results
Item Order Analysis

Item Order	N	Overall Accuracy (%)	Std. Error (%)
1	18	55.8	3.4
2	21	59.1	2.5
3	23	55.9	3.3
4	23	58.9	2.8

Table 2-8
Experiment 2-2b Results
Response Order Analysis

Response Order	N	Overall Accuracy (%)	Std. Error (%)
Severity-Frequency	59	54.1	2.5
Frequency-Severity	39	50.5	1.9

Summary

In sum, baseline results of Experiment 2-1, in which subjects in spatial conditions outperformed subjects in textual conditions, cannot be explained simply by presence of varying-width lines or labeled axes, nor by gender, compensation, or order effects. In support of prior alternative representations research, the alternative formats themselves led to significant performance differences. These differences were further investigated in Experiments 3-1 through 5-1.

Chapter 3. Interference

Imagery and Organization Hypotheses

Two hypotheses that focus on structure of alternative representations, organization and imagery, predict different patterns of results across the four study representations. For instance, an increase in organization across representations might have enabled improved memory performance (Bower & Clark-Meyers, 1980; Friendly, 1977; Norman, Brooks, & Allen, 1989, experiment 1; see also Rabinowitz & Mandler, 1983). From paragraph to outline there was an addition of hierarchical structure to sentences. The tree diagram retained this hierarchical structure, but added overt specification of the underlying severity and frequency dimensions. The matrix dropped hierarchical structure, but retained an overt specification of dimensions. It is possible, then, that increased organization permitted subjects greater ability to mentally organize side-effects information, in turn enabling improved recall performance. However, this ***organization hypothesis*** suggests improved performance from paragraph to outline, which did not occur,[7] as well as from

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[7]. The outline representation used here retained sentences, though not all outlines do. Effects of increase in organization, then, might have been masked by retention of sentential information. Support for this conjecture is demonstrated by analysis of performance across food nutrition filler tasks, described in Chapter 3. There, the outline is basically a structured list of items, rather than sentences; performance in outline and tree conditions did not differ, but exceeded performance in the paragraph condition, and lagged behind performance in the matrix condition. However, whether or not outline organization is masked by sentences, the organization hypothesis cannot explain all findings reported for subsequent experiments.

textual to spatial, which did occur.

Alternately, the two spatial representations may have afforded a mental image while the two textual representations were less likely to do so. That is, an ***imagery hypothesis*** suggests performance in spatial conditions would exceed that of textual conditions because the tree diagram and matrix enabled subjects to easily create mental pictures for use in retrieval of information.

These two hypotheses were tested in Experiments 3-1, 3-2 & 4-2. Although they make slightly different predictions for these four study representations, the two are not mutually exclusive. The imagery hypothesis implies that any spatial representation leads to better memory performance over any textual representation. This prediction makes sense when the spatial representation clarifies underlying stimulus dimensions, as do the tree diagram and matrix for severity and frequency information, but alternative spatial representations, with different organization, might not make target dimensions clear. For instance, a fan representation (see Figure A-7) separates the levels of one dimension and forms sub-trees from other dimensions. Emphasis of dimensions within a fan remains unclear, though; either spatial separation or prioritization of dimensions within the sub-trees might focus attention.[8] Similarly, sentences in a paragraph can be written in interesting configurations (e.g, a spiral; see Figure A-8), which may lead to an image that clearly does not yield easy access to underlying stimulus dimensions.

Thus, the imagery hypothesis depends in part on the organization hypothesis. An image alone will not allow easy access to information present in

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8. A fan representation has been used in concurrent studies by Day, who has found that a fan assists memory and inference performance compared to textual representations, but not as much as a tree representation.

a representation; it does only when the structure reflects underlying dimensions that are needed for retrieval (see Zhang, 1996). This reasoning suggests a "process model" that focuses on processing of alternative representations, describing how and what information may be accessed in an external representation or an image of one. A simple model for searching and retrieving is described next, together with research supporting both structural hypotheses.

Process Model

Both McGuinness (1986) and Day (1980) demonstrate cognitive consequences that follow from a variety of configural forms. That is, format of an external representation can affect how a task is performed. For instance, Bettman and Kakkar (1977), in a consumer decision-making study, analyzed product information acquisition among three groups of subjects. Groups received information in booklet form organized by product attribute, by brand, or in a brand by attribute matrix. The groups differed in information acquisition sequence; consumers acquired information "in that fashion which is easiest given the display used" (p. 237). Similarly, Zeitz and Spoehr (1989), on a troubleshooting task, first explicated the faulty device using either a depth-first or breadth-first representation. They found large differences between groups. Breadth-first subjects exhibited more efficient performance than depth-first subjects.

Therefore, alternative representations differ in what properties of a stimulus array they emphasize. On different cognitive tasks, this change in emphasis can lead to differences in information acquired across representations (Day, 1988; Kleinmuntz & Schkade, 1993; Schkade & Kleinmuntz, 1994). For instance, paragraph formats provide primarily serial order to given information. Similarly, outlines provide primarily serial, but also some hierarchical, order to given information. On the other hand, a matrix makes manifest two underlying dimensions of the information, and imposes few constraints on search order (Bettman & Kakkar, 1977). The matrix makes clear how specific items relate to each other along both dimensions; conversely, it de-emphasizes serial order. Alternatively, a tree diagram prioritizes one dimension over the other, enabling either breadth-first or depth-first search. A tree diagram serves well for tasks requiring knowledge of close familial relationships but not tasks using distant relationships (McGuinness, 1986). Thus, the steps that subjects take in processing (e.g., searching) tree diagrams differ from those taken for text and for matrices.

A ***process model*** provides an estimate of time and / or steps required to traverse a representation, for a given task, to obtain necessary information. McGuinness (1986) found that such an estimate, even a rough approximation counting number of mental steps, supported results on two tasks for two representations, a tree diagram and a matrix. Similarly, Larkin and Simon (1987) demonstrate how much processing is required for textual representations versus diagrams, on two problems. In the current research, subjects performed a cued recall of study information; subjects needed to search their internal representations of the study representations to recall severity and frequency information. A simple process model is presented for this task.

Model of Processing for Current Experiments

Simon (1989) distinguishes alternative representations on the basis of computationality, which partly explains the advantage of spatial over textual baseline representations. If two representations contain the same information, Simon claims they are informationally equivalent. If, in addition, one representation can be transformed into the other, and vice-versa, with only reasonable effort (in time or number of steps), and with no loss of information, then the two are computationally equivalent. Using the approach taken by Larkin and Simon (1987), the four alternative (hence informationally equivalent) representations used in the current research are not all computationally equivalent. The two textual representations require different types of processing than the two spatial representations.

Larkin and Simon (p. 69) describe how "differences in search strategies associated with different representations" lead to vastly different processing requirements. Search is much easier (for people, if not machines) with diagrams rather than lists. The four representations clearly demonstrate this conjecture. Paragraphs and outlines facilitate serial search, tree diagrams (and outlines, to some extent) either breadth-first or depth-first search, and matrices either row or column scan. Note, though, that both tree diagrams and matrices, but not paragraphs and outlines, enable rapid access (i.e., indexed by severity or frequency levels) to side-effects information.

On cued recall tasks, then, memory performance should differ between the two spatial representations and textual representations. Paragraphs and outlines provide little structure beyond serial order useful for search and retrieval (as well as for associations among items, unless the information was reorganized by the subject after acquisition; cf. Tulving, 1962). When presented with cues (i.e., side-effects), subjects in these conditions should have difficulty retrieving specific information (i.e., associated levels of severity and frequency). This difficulty should be reflected in long response time necessitated by serial search, or, on a time-limited task, low accuracy. In addition, because of serial search, performance should be best for primacy information (i.e., that positioned early in the display). In contrast, both tree diagrams and matrices provide easy access, direct links, from cues to dimension information. This ease should be reflected in short response time enabled by indexed access, or, on a time-limited task, high accuracy across all cues (primacy effects should be lessened). Thus, this simple process model predicts different memory performance across the alternative representations.

Alternative Internal Representations

The discussion so far applies to external representations, that is, those actually presented to subjects. However, the two spatial representations can also serve as retrieval structures (Chase & Ericsson, 1982), that is, mental images which provide the same access using cues as the external objects.[9] The process model states that external tree diagrams and matrices provide efficient retrieval cues whereas paragraphs and outlines do not. Experiments 3-1 & 3-2 were intended to demonstrate support for the imagery hypothesis, showing that external spatial representations are reflected by analogous internal structures, while non-spatial representations lead to non-spatial internal structures.[10] Process model predictions, then, would apply to these mental images.

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9. A retrieval structure need not be an explicit mental image. For instance, Chase and Ericsson (1982) demonstrate how a subject functionally used a tree diagram to remember long strings of digits, though the hierarchy was not visual. An important distinction has been made between object or sensory imagery, the ability to perceive attributes of an object, and spatial imagery, the ability to perceive relations within an object or among objects (see Watson, 1994, for a review). The imagery hypothesis here would claim that aspects of both types of imagery are necessary to recall specific side-effects information.

10. Following text comprehension research by Kintsch (1988), it is assumed that textual representations lead to propositional structures.

Initial Support from Baseline Experiments

The model of processing just described is used to explain results of subsequent experiments, but a re-analysis of baseline results provides initial support for it, and for the imagery hypothesis. Specifically, data were re-analyzed from all 118 subjects from Experiments 2-1 & 2-2 who received the baseline filler task. Study information was separated into four groups, based on location of side-effects in the study displays. The Initial group included eight side-effects generally highest in severity and frequency; the Final group included eight side-effects generally lowest in severity and frequency; the Central group included eight side-effects neither high nor low in severity and frequency; and the No-Information group included four side-effects for which no severity or frequency information was given.[11] A repeated-measures analysis of variance examined both differences across study representations for each group and differences across groups for study representations.

Figure 3-1 plots results; Table 3-1 tabulates results. Subjects in spatial conditions outperformed subjects in textual conditions in all four location groups (all $F_{1,116} \geq 11.88$, $p < .0008$). Location, too, was significant ($F_{3,114} = 15.61$, $p < .0001$), with earlier-positioned side-effect information better recalled.

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[11]. Three different assignments of specific side-effects to groups were analyzed, all with similar patterns of results. Thus, results do not depend on how "highest" and "lowest" are defined for combined levels of severity and frequency.

Table 3-1
Experiments 2-1 & 2-2 Results
Position of Information

Study Rep.	N	Initial Gp. Accuracy (%)	Central Gp. Accuracy (%)	Final Gp. Accuracy (%)	No Info Gp. Accuracy (%)
Paragraph	28	46.0	51.6	45.3	29.0
Outline	28	52.7	51.8	37.9	44.6
Tree	32	66.4	66.6	56.1	70.3
Matrix	30	61.5	66.3	50.0	65.8

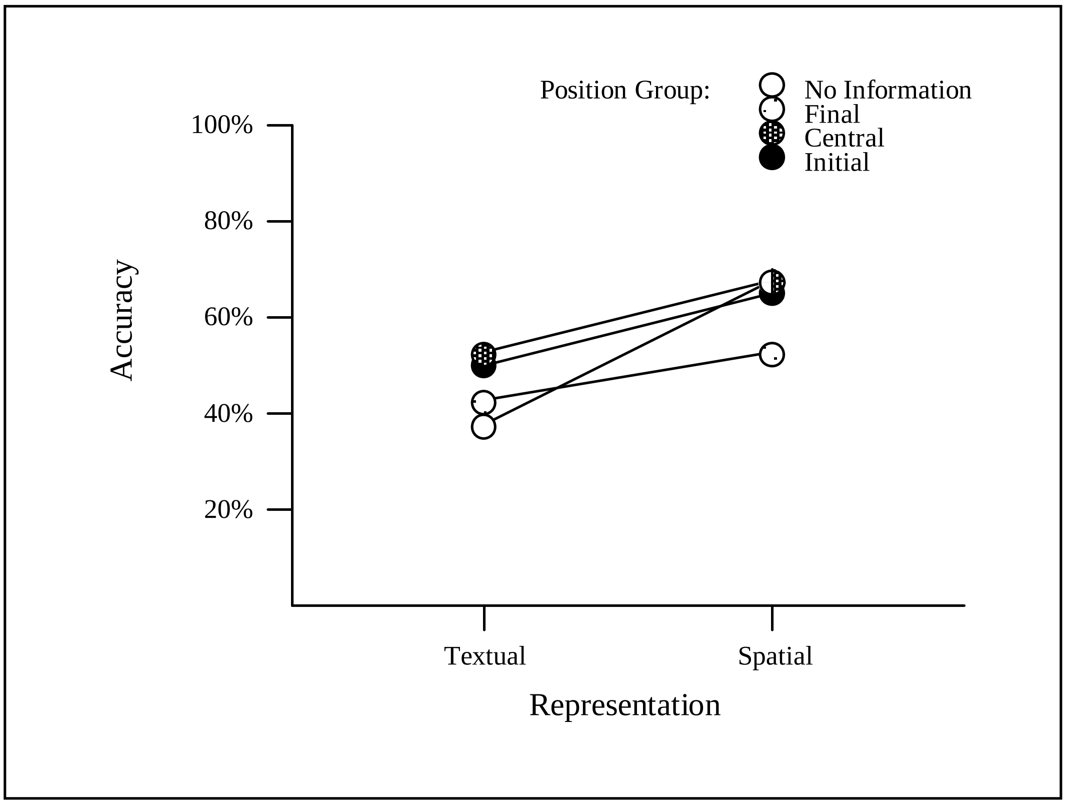

Figure 3-1
Experiments 2-1 & 2-2 Results
Position of Information

Importantly, though, the interaction between representation and group location was significant ($F_{3,114}$=3.54, ***p***<.02), such that subjects in spatial conditions were less affected by information position than subjects in textual conditions. The Outline condition contributed considerably to this interaction; performance dropped significantly from Initial to Final groups. Also, the No-Information group was positioned away from all other information in the spatial conditions, yet still resulted in high performance. (Interestingly, the No-Information group was positioned atop all other information in the textual conditions, yet did not result in high performance, perhaps because these displays did not make the lack of severity or frequency information obvious.)

These results support process model predictions. Textual displays seem to lead to serial search while spatial displays enable indexed search. Results also support imagery hypothesis predictions. That is, an explanation based solely on propositional encoding requires for spatial but not textual representations additional propositions for indices, dimensional priority, and positional cues. In contrast, an explanation involving mental images of study displays requires no additional premises. Apparently, then, search and information retrieval can be performed on images of study displays.

Experiments 3-1 & 3-2 further tested the imagery hypothesis by attempting to demonstrate selective interference, where matching internal structures interfere with each other. For instance, subjects in the Tree-Tree condition (who receive a tree study representation and then encounter a second tree diagram in the filler task) would be expected to perform more poorly than subjects in Tree-No Tree conditions (who do not encounter a second tree diagram), if indeed matching internal structures interfere with each other. Similarly, subjects in the Matrix-Matrix condition (who receive a matrix study representation and then encounter a second matrix in the filler task) would be expected to perform more poorly than subjects in Matrix-No Matrix conditions (who do not encounter a second matrix). However, no interference should occur for subjects who study either a paragraph or an outline, because these subjects should not create images of the study displays.

Extension of Skilled Memory Theory

The expectation that spatial representations lead to spatial (hereafter called "imagistic") internal structures follows from work by Ericsson and Kintsch (1995), who argue that subjects experienced in a domain have learned to encode and retrieve information from a stimulus array using efficient structures, in effect expanding their working memory capacity. Ericsson and Kintsch describe how skilled subjects extend their short-term working memory (ST-WM) capacities to involve long-term working memory (LT-WM). A key feature of their theory is the ability of skilled subjects to form retrieval structures kept in ST-WM that access information in LT-WM. They demonstrate these structures for skilled subjects in text comprehension, chess playing, medical diagnostics, abacus use, waiting tables and memory for lengthy digit sequences. The current research attempts to extend their theory by showing that novices encountering spatial representations can use the same strategy as experts: Images result from study of spatial representations and serve as retrieval structures for information from long-term memory. This prediction requires three assertions to be verified, that internal representations can indeed be analogous to external representations, that spatial internal representations can interfere with each other, and that representations matching in format, in particular, will affect each other. Prior research supports each assertion.

Imagery

Prior research has shown that some subjects can create an image of an external representation. For instance, Hatano and Osawa (1983) found mental abacus calculation experts apparently represent digits in an abacus image. Similarly, Ericsson and Oliver (in Ericsson & Staszewski, 1989) found that a chess master appeared to retrieve board information using an image of the chess board. Visual imagery research (e.g., Kosslyn, 1975; Paivio, 1983), has shown that many individuals can conjure and manipulate pictures of external objects, or even abstract shapes (Santa, 1977; Shepard & Metzler, 1971). Related research deals with cognitive maps. For instance, Stevens and Coupe (1978) and Holyoak and Mah (1982) found that individuals estimate geographical distances as if they are viewing a map, albeit somewhat distorted (see also McNamara, 1991; Ward & Reingen, 1990). Thus, some evidence suggests that subjects can internally represent given information in nearly equivalent form.[12]

Interference

Prior research has shown that spatial and imagery processes share

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12. An image need not reflect a one-to-one mapping of the external to internal world (Day, 1988; Paivio, 1975, 1983; Rubin, 1988; see Shepard & Chipman, 1970, on second-order isomorphism). Extensive research on mental models (e.g., Hanisch et al., 1991; Kieras & Bovair, 1984) demonstrates that subject behavior can be modeled by abstract mental representations that do not necessarily reflect real-world objects. Similarly, textual input that describes spatial layouts, such as rooms of a house (cf. Bower & Morrow, 1990; Glenberg, Meyer, & Lindem, 1987) might involve either propositional or imagistic representation. The claim here, however, is that some internal representations do reflect effects of an external representation; alternative internal representations in ST-WM act just like alternative external representations, notably in how they provide retrieval cues to information in LT-WM. This is the argument for spatial representations (tree diagram, matrix).

resources (e.g., in the visuo-spatial sketchpad proposed by Baddeley & Hitch, 1974, 1994), that spatial working memory resources are separate from textual working memory resources (Shah & Miyake, 1996), and that spatial tasks can interfere with each other. For instance, Brooks (1968), in one task, had subjects mentally trace an uppercase block letter (e.g., F) and categorize each corner as either at the top or bottom or not. Time to respond was measured. Brooks cleverly incorporated two conditions, the first a visual interference condition in which subjects responded by pointing to a "Y" or "N" on a display, the second a verbal condition in which subjects responded by saying "yes" or "no". Subjects were faster in the verbal condition than in the visual condition. In a second, control, task, subjects were asked to recall from sentences that had been read to them whether or not each word was a noun. Again there were two conditions, the first a verbal interference condition in which subjects responded by saying "yes" or "no", the second a pointing condition in which subjects responded by pointing to a display. In this task subjects in the pointing condition were faster than those in the verbal condition. These results were taken to mean that subjects were scanning a mental representation analogous to the physical array. Follow-up work demonstrated that it was spatial, and not just visual, processes that were affected (see Baddeley & Hitch, 1994).

Selective Interference

Interference literature suggests that interference builds up the more similar items are to previously experienced items (e.g., Wickens, 1970). Two internal structures that match in format, then, might interfere with each other more than two non-matching internal structures. Most studies that investigate spatial interference do not consider alternative structures, but instead effects of intervening tasks themselves (listening, tapping, articulation, etc.) on spatial memory (e.g., Jones, Farrand, Stuart, & Morris, 1995; Smyth & Scholey, 1994). However, some studies do provide support. For instance, den Heyer and Barrett (1971) had subjects study a six-by-four matrix filled with eight letters. An intervening task was either verbal (subjects added numbers) or visual (subjects saw three two-by-four matrices filled with dots). On a test of letter identity neither task largely affected results; according to theories of spatial memory (see Watson, 1994) and the current process model, letter identity can be encoded propositionally, so interference would not be expected. On a test of letter position, however, the visual task resulted in poorer performance than the verbal task. Item position is presumed to be coded visually (Watson, 1994), and an intervening display can interfere with position information. Similarly, Elmes (1988) demonstrated retroactive interference using radial mazes and playing cards. In one experiment, Elmes determined that savings during relearning of a radial maze was adversely affected by similarity of an intervening learned maze. In a second experiment, Elmes replicated these results using the card game "concentration".

The current research, too, relies primarily on retroactive interference. Proactive selective interference would occur if performance on the filler task (where subjects encounter a second representation from an unrelated content domain) decreases only when the study representation matches the filler representation. This was tested. More importantly, though, retroactive selective interference would occur if performance on the recall test decreases only when the study and filler representations match. However, either type of selective interference would support the imagery hypothesis.

Summary

In sum, the simple process model described above suggests that memory performance in spatial representation conditions should exceed performance in textual representation conditions. The imagery hypothesis suggests that subjects use a process similar to imagery for spatial representations. Together, they imply that both tree and matrix representations should provide an imagistic internal representation that assists memory performance, with no particular advantages for either image for this memory test. Meanwhile, both paragraph and outline representations should provide propositional internal representations, again with no particular advantages for either for this memory test. Experiments 2-1 & 2-2 supported these ideas; Experiments 3-1 & 3-2 explored them further.

Experiment 3-1 · Selective Interference I

Experiments 3-1 & 3-2 employed carefully designed filler tasks in an attempt to selectively interfere with study information (see Table 3-2 for a design overview). Content was kept constant, as a control, across the four filler representations of Experiment 3-2. However, the actual content should not affect memory performance; instead, the format represented by the filler

Table 3-2
Overview of Experiments 3-1 & 3-2

task should affect performance.[13] Task requirements, too, were kept constant

Exp. #	Study Reps.	Filler Reps.	Filler Content	Filler Task
3-1	Paragraph Outline Tree Matrix	Textual* Tree Matrix	general side-effects questions parse trees progressive matrices	answer questions from previous knowledge solve arithmetic problems solve symbolic problems
3-2	Paragraph Outline Tree Matrix	Paragraph Outline Tree Matrix	food nutrition information	answer questions about display information

* baseline filler task from Experiment 2-1

across the four filler representations of Experiment 3-2. However, filler tasks requiring similar cognitive effort should not affect memory performance; again, the format represented by the filler task should affect performance. Thus, Experiment 3-1 used two new filler tasks that differed in content and task requirements but retained key representational formats. One filler task retained tree diagram form, but presented a series of mathematical problems to be solved using parse trees. The other filler task retained matrix form, but presented a series of progressive matrix problems. There were eight new conditions, the same four study representations crossed with these two filler tasks; performance was compared against baseline performance of Experiment 2-1 for each study condition. Experiment 3-1 was expected to show that filler representations selectively interfere with memory for study representation information, supporting imagery hypothesis and process model predictions.

13. Of course, highly similar content can cause proactive interference (Wickens, 1970), even for spatial information (Elmes, 1988). Thus, content for these filler tasks never involved side-effects severity and frequency information.

Method

Subjects. Experiment 3-1 used 178 Duke University undergraduate students, including subjects from Experiments 2-1 & 2-2. Details of number of participants per condition are given in a table below.

Materials. Subjects were handed a booklet of four pages. All materials for Experiment 3-1 were identical to those of Experiment 2-1, with the exception of the filler task. For Experiment 3-1, two new filler tasks were used. The first involved tree diagrams (Figure B-2); subjects tried to solve mathematical "parse tree" problems by successively applying a node operator to results of its two branches. This filler task was expected to interfere with the Tree study representation but no other study representation. The second filler task involved matrices (Figure B-3). Subjects had to determine the correct symbol or symbols belonging in the bottom right cell of a three by three grid, given relationships among symbols in the other eight cells. These problems are progressive matrix problems (Raven, cited in Carpenter, Just, & Shell, 1990). This filler task was expected to interfere with the Matrix study representation but no other study representation.

Procedures. Experiment 3-1 followed the exact same procedures as Experiment 2-1.

Expected Results

The 12 conditions can be described in terms of which study and filler representations subjects received; for simplicity, the baseline filler is called Textual, since it asked a series of questions in sentence form. Thus, Tree-Textual subjects received a Tree diagram for study and the baseline filler, while Matrix-Matrix subjects received a Matrix for study as well as for the filler. The 12 possibilities are detailed in Table 3-3, along with expected results (italics highlighting selective interference conditions) for each.

Figure 3-2 graphically depicts results predicted for selective interference. Memory performance was expected to decline for Matrix-Matrix subjects, but not Matrix-Tree subjects, relative to performance for Matrix-Textual subjects. Similarly, performance was expected to decline for Tree-Tree subjects, but not Tree-Matrix subjects, relative to performance for Tree-Textual subjects. According to the imagery hypothesis, both study and filler spatial representations should give rise to their characteristic imagistic internal representation. Matching internal representations should interfere with each other, hurting memory performance. Non-matching representations should not interfere, though, even for different spatial representations (e.g., Tree-Matrix). Interference should occur when access to the imagistic internal representation is obstructed; retrieval of specific side-effect information (i.e., severity and frequency information) from LT-WM should be most affected when two co-existing representations in ST-WM are similar (e.g., two tree diagrams). Retrieval should be less affected when two co-existing representations are not similar (e.g., a tree diagram and a matrix, or a tree diagram and a propositional structure created from a textual representation).

Results and Discussion

Figure 3-3 plots results of Experiment 3-1; Table 3-4 tabulates results. As in baseline results, study representation led to a highly significant main effect

Table 3-3

Conditions in Experiment 3-1

Condition	Description	Expected Result
Paragraph-Textual	Paragraph study, baseline filler	moderate performance*
Outline-Textual	Outline study, baseline filler	moderate performance*
Tree-Textual	Tree diagram study, baseline filler	good performance*
Matrix-Textual	Matrix study, baseline filler	good performance*
Paragraph-Tree	Paragraph study, parse tree filler	moderate performance
Outline-Tree	Outline study, parse tree filler	moderate performance
Tree-Tree	Tree diagram study, parse tree filler	***moderate performance***
Matrix-Tree	Matrix study, parse tree filler	good performance
Paragraph-Matrix	Paragraph study, progressive matrix filler	moderate performance
Outline-Matrix	Outline study, progressive matrix filler	moderate performance
Tree-Matrix	Tree diagram study, progressive matrix filler	good performance
Matrix-Matrix	Matrix study, progressive matrix filler	***moderate performance***

* actual results from Experiment 2-1

($F_{3,166}$=8.27, p<.0001), with t-tests showing that textual (Paragraph and Outline) conditions did not differ, nor did spatial (Tree and Matrix) conditions, but textual differed from spatial. The filler task did not affect memory performance itself ($F_{2,166}$<1), nor did it interact with representation ($F_{6,166}$<1). This last finding, importantly, implies that no selective interference occurred. Otherwise, the pattern of performance across study representations would have differed for the different filler tasks.

Thus, Experiment 3-1 failed to support the imagery hypothesis for the baseline Experiment 2-1 findings. However, neither experiment fully supported the organization hypothesis. According to the organization

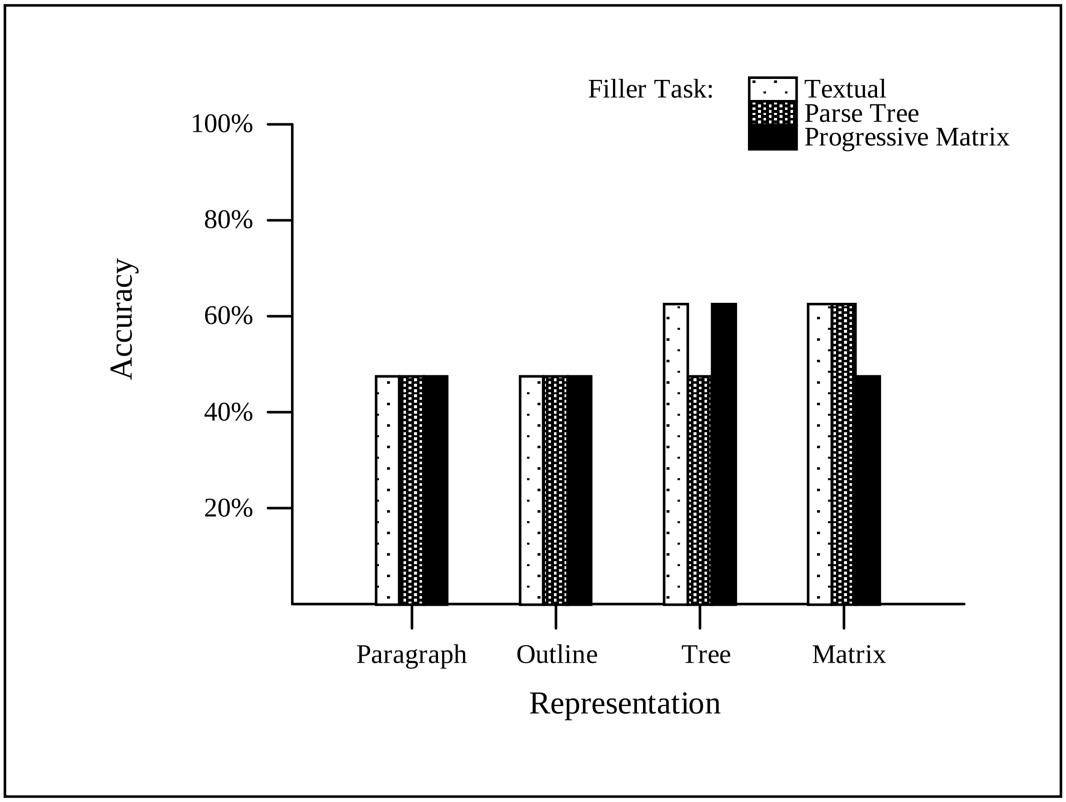

Figure 3-2
Expected Results
Selective Interference

hypothesis, an increase in organization across all four study representations should lead to improved memory performance; the nature of the filler task should play no role. While in this experiment filler indeed played no role, in both experiments performance in the Outline condition was no better than performance in the Paragraph condition. Therefore, more than simply amount of organization was involved. These results are addressed in a general discussion section below.

Table 3-4
Experiment 3-1 Results
Selective Interference

Study-Filler Reps.	N	Overall Accuracy (%)	Std. Error (%)
Paragraph-Textual	28	45.0	2.4
Paragraph-Tree	10	47.7	4.6
Paragraph-Matrix	10	47.7	5.4
Outline-Textual	28	47.1	2.5
Outline-Tree	10	55.5	3.2
Outline-Matrix	10	52.1	5.2
Tree-Textual	22	63.6	3.1
Tree-Tree	10	57.5	3.4
Tree-Matrix	10	57.9	5.7
Matrix-Textual	20	59.1	2.2
Matrix-Tree	10	62.3	4.4
Matrix-Matrix	10	60.2	6.4

Experiment 3-2 · Selective Interference II

Experiment 3-1 failed to find selective interference. However, it was not completely controlled. For instance, the textual filler task (from Experiment 2-1) was neither paragraph nor outline. Similarly, the contents and task requirements of the parse trees and progressive matrices were completely different. Although, according to reasoning given above, neither content nor task requirements should play a role in selective interference, the design of Experiment 3-1 did not disallow these potential confounds.

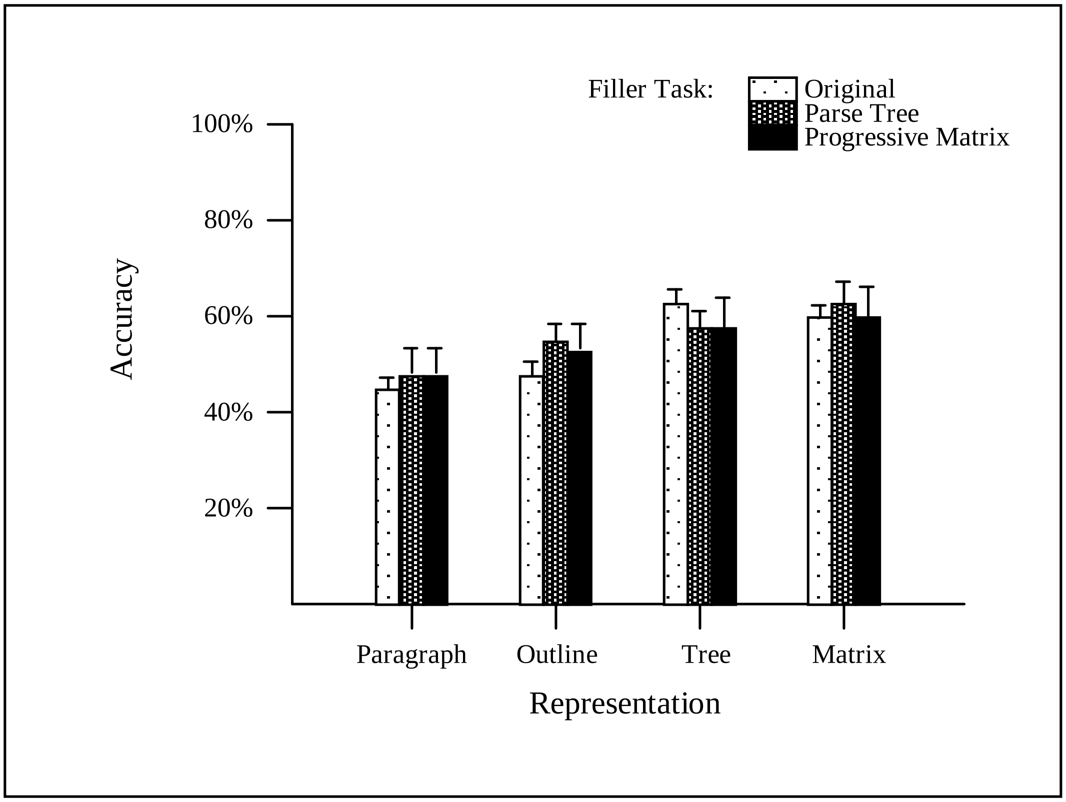

Figure 3-3
Experiment 3-1 Results
Selective Interference

Experiment 3-2 cast the filler task into four alternative representations matching the four study representations. By crossing each study representation with each filler representation, there were potentially 16 conditions; to increase statistical power based on subject availability, 13 key conditions were included.[14] Experiment 3-2 was intended to obtain selective interference using a carefully controlled filler task.

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14. Three outline study conditions were omitted in Experiment 3-2. Only one textual study representation (Paragraph) was retained, since paragraph and outline baseline study conditions led to equivalent performance. However, Outline-Outline was also retained to ensure that no selective interference occurred in that condition.

Method

Subjects. A total of 85 Duke University undergraduate students participated. Details of number of participants per condition are given in a table below.

Materials. Subjects were handed a booklet of four pages. All materials for Experiment 3-2 were identical to those of Experiment 2-1, with the exception of the filler task. For Experiment 3-2, the filler task used information from an unrelated domain, food nutrition, presented in one of four alternative representations: The Paragraph (Figure B-4) described food nutrition information in sentences, the Outline (Figure B-5) as a structured list, the Tree (Figure B-6) and Matrix (Figure B-7) in spatial configurations. Subjects answered ten comprehension questions about the food nutrition information presented. The task required of subjects, simply answering a series of questions, did not differ from Experiment 2-1; only the nature of the questions differed. Alternative filler representations were constructed to appear similar to the study representations, and spatial filler representations were expected to selectively interfere with matching study representations.

Prior research by Day and colleagues (unpublished data) has already investigated memory and comprehension performance for this nutritional information for two alternative representations: Matrices were shown to assist performance relative to Outlines. Food nutrition questions were selected for use here as a filler task precisely because of these prior results. That is, Experiment 3-2 attempted to demonstrate that retrieval structures arising from spatial representations can interfere with each other. The filler task had to result in different retrieval structures, but remain controlled in information content. The alternative filler representations of this experiment filled this need, differing solely in format, yet, because of previous results, apparently yielding different imagistic structures.

Procedures. Experiment 3-2 followed the exact same procedures as Experiment 2-1.

Expected Results

Experiment 3-1 used spatial filler representations in which content varied across representations. However, according to reasoning given above, format of study and filler, not content nor task requirements, should affect memory performance (see Kleinmuntz & Schkade, 1993). Thus, expected results for Experiment 3-2 were similar to those for Experiment 3-1. There should be selective interference only in the Matrix-Matrix and Tree-Tree conditions; only these conditions should decrease in memory performance from baseline results of Experiment 2-1.

Results and Discussion

Figure 3-4 plots results of Experiment 3-2; Table 3-5 tabulates results. Again, study representation affected memory ($F_{3,72}$=5.46, ***p***<.002), with subjects in spatial conditions outperforming subjects in textual conditions, in a pattern similar to baseline results; in fact, the interaction was not significant between experiment (Experiment 2-1 vs. 3-2) and study condition ($F_{3,175}$=1.08, ***ns.***). The different filler representations did not affect memory performance ($F_{3,72}$<1), nor was there an interaction between filler and study representation ($F_{6,72}$=1.45, ***ns.***). This last finding, again, implies that no selective interference occurred. Otherwise, the pattern of performance across study representations would have differed for the different filler representations.

Table 3-5
Experiment 3-2 Results
Selective Interference with Controlled Filler Stimuli

Study-Filler Reps.	N	Overall Accuracy (%)	Std. Error (%)
Paragraph-Paragraph	5	44.6	4.2
Paragraph-Outline	5	53.6	6.6
Paragraph-Tree	6	51.5	6.4
Paragraph-Matrix	6	44.0	4.5
Outline-Paragraph		(not done)	
Outline-Outline	6	57.1	4.6
Outline-Tree		(not done)	
Outline-Matrix		(not done)	
Tree-Paragraph	7	58.4	3.5
Tree-Outline	7	61.0	4.8
Tree-Tree	7	63.3	5.7
Tree-Matrix	6	64.9	3.5
Matrix-Paragraph	6	61.9	5.4
Matrix-Outline	8	49.3	4.4
Matrix-Tree	8	64.3	5.5
Matrix-Matrix	8	66.1	3.5

Further analysis did reveal a significant interaction, which was not found for Experiment 3-1. Specifically, when the two textual study representations were combined, the two spatial study representations combined, the two textual filler representations combined, and the two spatial filler representations combined, an interaction between spatial/non-spatial

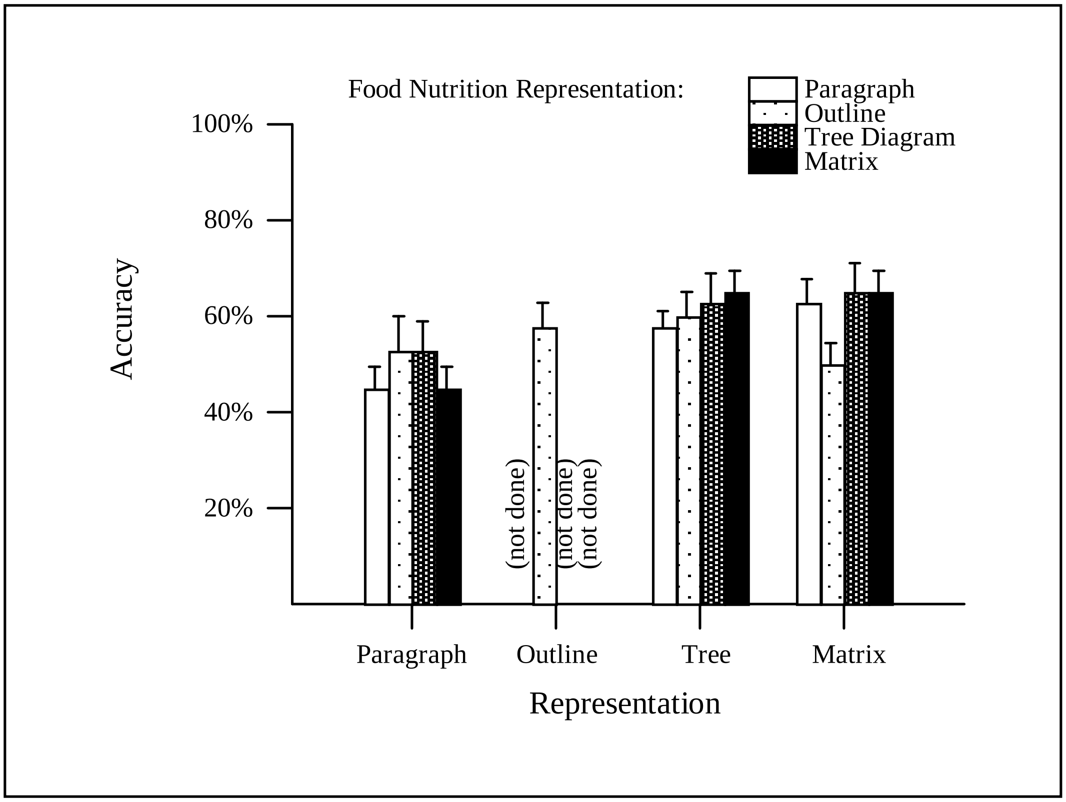

Figure 3-4
Experiment 3-2 Results
Selective Interference with Controlled Distractor Stimuli

study representation and spatial / non-spatial filler reached significance ($F_{1,81}$=4.13, p<.05). Figure 3-5 shows this interaction. Interestingly, the effect is opposite that predicted by selective interference: Spatial filler representations assisted performance for spatial study conditions, while textual filler representations had little effect for either spatial or textual study conditions. The magnitude was rather small, though, to label the cause of this interaction selective facilitation.

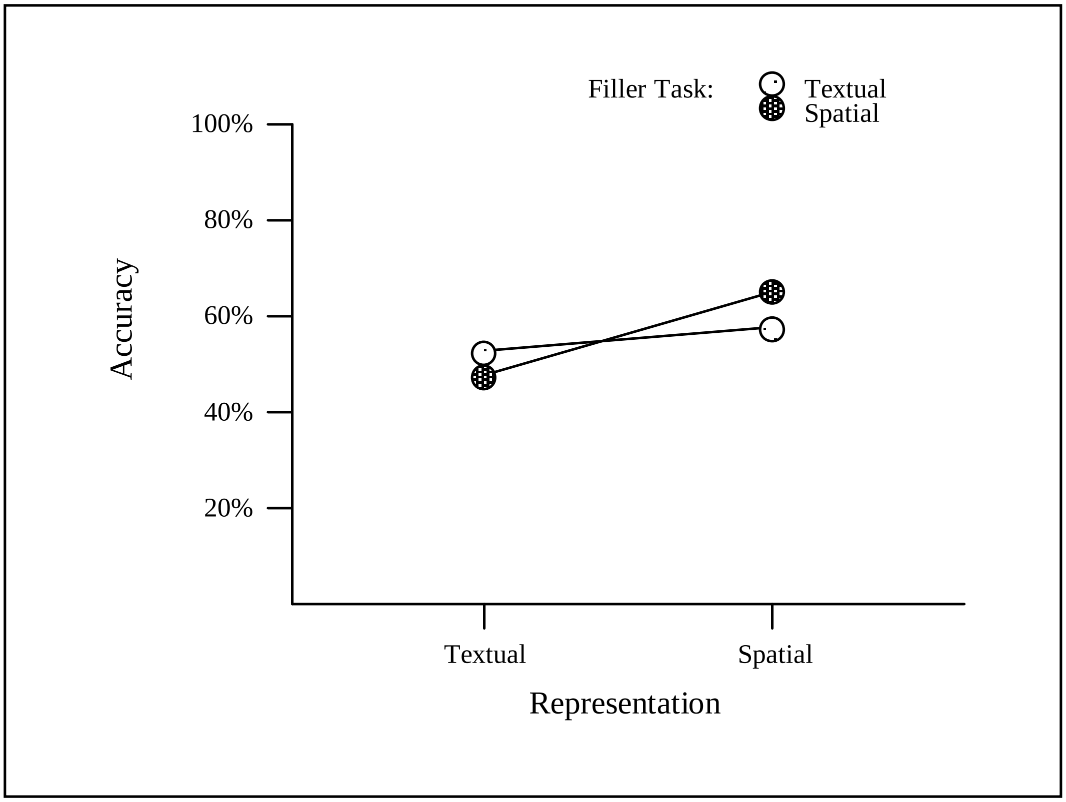

Figure 3-5
Experiment 3-2 Results
Combined Textual vs. Spatial

General Discussion

The results from Experiments 3-1 & 3-2 failed to support a finding of selective interference. It was predicted that memory performance would drop in the Tree-Tree and Matrix-Matrix conditions of both experiments, relative to performance in the Tree-Textual and Matrix-Textual baseline conditions of Experiment 2-1. This prediction did not hold. Instead, regardless of filler task, subjects in spatial study conditions outperformed subjects in textual study conditions.

These findings do not necessarily undermine the imagery hypothesis, however. Because subjects in spatial study conditions consistently performed well, they still might be forming mental images to use as retrieval structures during the memory task. If so, these images were impervious to the particular filler representations used here. There are several possible reasons for these findings.

First, the filler representations might not closely enough resemble the study representations. For instance, the side-effects tree diagram has four branches even in length, and bubbles as nodes, whereas the parse tree problems have varying width and height and symbols as nodes. Similarly, the side-effects matrix has five rows by four columns with two side-effects per filled cell and seven empty cells, whereas the food nutrition matrix has eight rows by three columns with check marks in exactly one-half of all cells. These differences might allow subjects to easily differentiate information between matching representations. The fact that study and filler always contained different information content also helped subjects to separate the representations.

Second, the filler representations may not have included enough information to tax working memory. In partial support of this conjecture, performance on the filler tasks themselves was analyzed. While answers to baseline filler questions could not be scored as correct or incorrect, they could be for the parse tree, progressive matrix, and food nutrition filler tasks. For Experiment 3-1, the progressive matrix task turned out to be marginally easier for subjects than the parse tree evaluation task (90% vs. 79% correct; $F_{1,72}=3.87$, $\boldsymbol{p}<.05$). However, importantly, the interaction between study representation and filler task was not significant ($F_{3,72}=1.64$, ***ns.***). For Experiment 3-2 filler representations, Matrix turned out to be somewhat easier for subjects than

Paragraph (93% vs. 76% correct), with Tree and Outline falling in between (81% and 85% correct; $F_{3,72}=3.07$, $p<.03$), but again the interaction between study representation and filler task was not significant ($F_{6,72}=1.22$, ***ns.***). Thus, although the specific filler representation affected results on the filler task, it cannot explain the pattern of results across study representations on the memory task.

Third, subjects may have been given enough time to create non-overlapping retrieval structures. Subjects were not under severe time pressure; they were given three minutes for both study and the filler task, which may have been sufficient for them to determine strategies to access information. Recall the significant spatial/non-spatial study and spatial/non-spatial filler interaction. Subjects in spatial study/spatial filler conditions may have been forced to strategically separate study and filler imagistic representations, which may have facilitated, rather than interfered with, performance. Similar reasoning suggests that, because they were instructed to solve filler problems but not to study the filler representations, subjects did not implicitly encode the filler information (or, at least, the filler representation). Since a test of memory for filler information was not included in the current research, only an extrapolation from their performance on the filler tasks is possible, and that suggests there was no effect of filler representation on memory for study representations.

Further, Ericsson and Kintsch (1995) propose that "skilled subjects can acquire memory skills suited to their working memory needs that allow them to overcome problems of proactive and retroactive interference" (p. 218). While experience with medication information is the subject of Chapter 4, the current subjects might be experienced enough with experimental procedure generally, and medication information specifically, that they were able to separate study from filler information using recency and elaborative encoding mechanisms, as

Ericsson and Kintsch describe.

Finally, the imagery hypothesis may, of course, not hold. However, the organization hypothesis alone cannot fully explain results such as textual representations yielding equal performance and the interaction between spatial / non-spatial study and spatial / non-spatial filler conditions. It is certainly the case, from the current research and much prior alternative representations research, that tree diagrams and matrices assist performance by providing easy access to information they contain. It is also apparent from existing research that subjects create mental images. The imagery hypothesis, then, is still relevant even though selective interference is not.

Summary

In sum, Experiments 3-1 & 3-2 failed to support selective interference but do not undermine the imagery hypothesis. In the next chapter, level of experience with side-effects information is considered. Results from this chapter and the next are reassessed in the final chapter.

Chapter 4. Experience

Experiments 4-1 & 4-2 explored the effect of experience on memory performance across study representations. Experience was expected to attenuate the effect of study representation, that is, the baseline pattern of results found with novice undergraduate students was expected to change with experienced subjects. This prediction introduces issues of possible interaction between experience and external representation.

Interaction between Experience and External Representation

An interaction between experience and representation can arise under several circumstances. Representations might affect the process of gaining experience. Novices and established experts might use provided representations differently, or generate different ones. Investigations may involve a single representation, alternative representations, or multiple representations that are not informationally equivalent. This section examines investigations that consider how cognitive task performance changes as level and type of expertise, and number and type of external representations, vary.

Possible Outcomes

Figure 4-1 shows four possible outcomes for an external representation

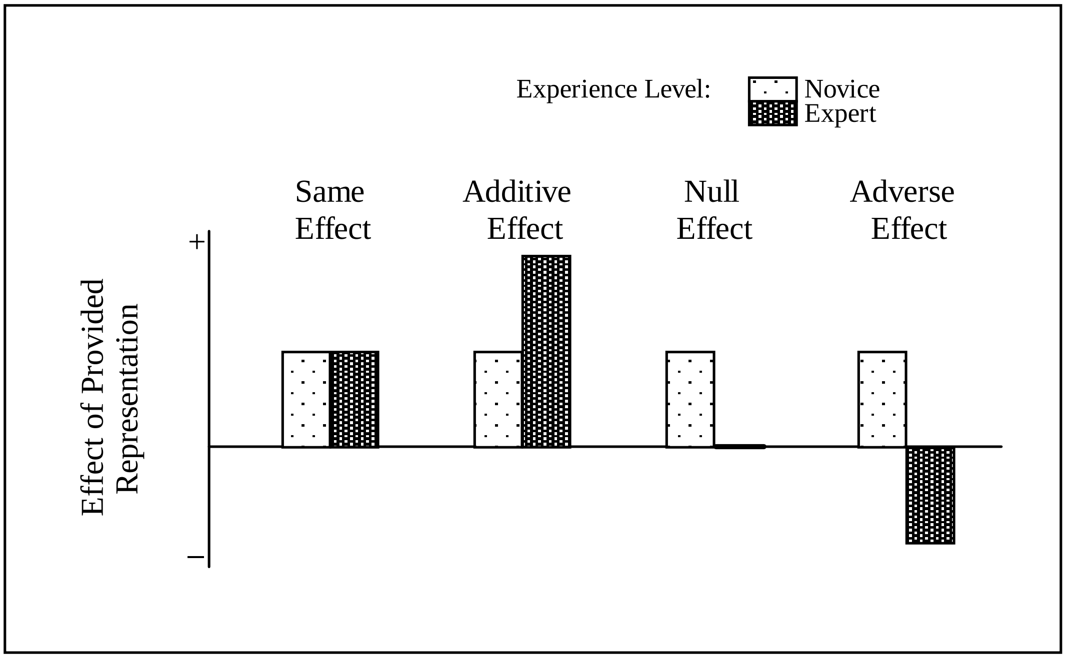

Figure 4-1
Possible Outcomes on Expert, Novice Performance
Provided Representation

on expert performance when the representation is created by investigators and provided to subjects. Figure 4-2 shows these four outcomes for alternative textual versus spatial provided representations. Outcomes, described next, are labeled Same Effect, Additive Effect, Null Effect, and Adverse Effect. Both figures assume a fixed level of modest benefit for novices, a sensible assumption based on results from most representation research, including Experiment 2-1, that uses subjects who are, generally, novices.

Same Effect. The Same Effect predicts that a provided representation should assist performance equivalently for experts and novices. Alternative

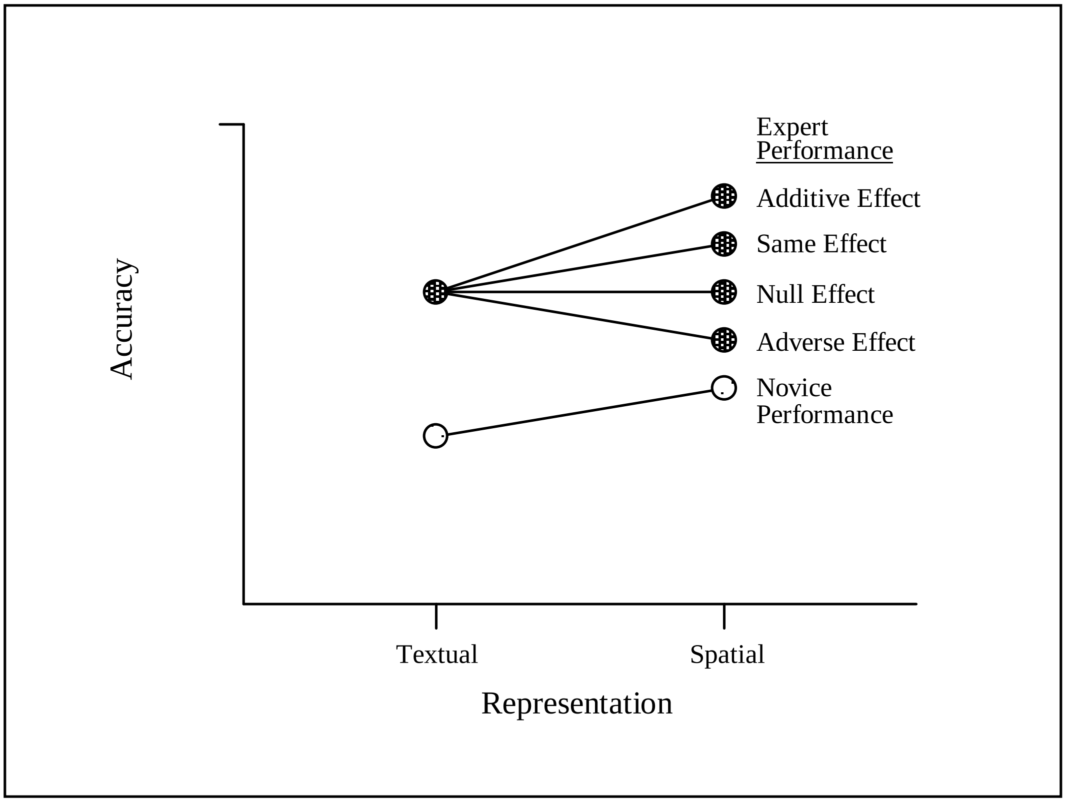

Figure 4-2
Possible Outcomes on Expert, Novice Performance
Alternative Textual, Spatial Representations

representations, too, should assist equivalently; the advantage of spatial over textual representations for novices should hold for experts as well. Experience, according to this prediction, should yield no particular advantages in using external representations.

Additive Effect. The Additive Effect predicts that an external representation should assist expert performance more than novice performance, because expert knowledge includes strategies for performing standard tasks in their domain of expertise (Glaser & Chi, 1988; Shanteau, 1988). One strategy is knowing how to represent given information, or how to use a given representation, to perform the task (Chi et al., 1981; Larkin & Simon, 1987; Simon & Hayes, 1976). This

Additive Effect seems intuitively sensible: External representations generally assist cognitive task performance (e.g., by reducing cognitive load or providing retrieval cues); they should assist already good performance even more. Since expert familiarity presumably encompasses most domain-relevant external representations, a provided representation should assist expert performance even when it is not one the expert would normally choose, as long as it makes underlying dimensions clear. For alternative representations (as opposed to simply a given provided representation), there should be a greater difference between expert and novice for spatial rather than textual representations.

Null Effect. The Null Effect predicts, due exactly to already good (but, for discussion purposes, below ceiling) expert performance, that an external representation should have no effect on expert performance. Experts come to a testing situation ready to use their knowledge and strategies. External representations are not necessarily needed (cf. Mayer & Gallini, 1990, p. 718), and spatial representations should provide no additional benefit over textual representations. A standard finding from the expertise literature holds that experts generally process at a structural level while novices process at a superficial level (Boster & Johnson, 1989; Chase & Simon, 1973; Chi et al., 1981; Halpern & Bower, 1982; Miller & Stigler, 1991; Weiser & Shertz, 1983). An external representation, then, would benefit only novices, because experts do not need added structure. Expert performance should be unaffected, though still better than novice performance.

Adverse Effect. The Adverse Effect predicts that an external representation should adversely affect expert performance, while still assisting novice performance. How might an external representation interfere with expert performance? At least two explanations apply.

A first explanation posits an interference between external and internal representations. Experts abstract internal representations for domain-relevant items (diSessa, 1985; Dreyfus & Dreyfus, 1984), perhaps automatically. If so, abstraction of a provided external representation might conflict with their existing internal representations. For instance, expert readers rarely encounter trouble with fonts; they are familiar with many, and read them (like this, or this, ***or this***) with ease. Yet some fonts (i.e., external representations), might hinder reading (like this), at least initially (cf. Burt, Cooper, & Martin, 1955). Similarly, many cognitive scientists claim that experts proceduralize what begin as declarative rules (Anderson, 1983; Dreyfus & Dreyfus, 1984). When asked to express rules that they follow during task performance (for instance, during knowledge engineering of an expert system), or even when forced to follow an external representation of provided rules, experts could fail. Novices, though, presumed to have memorized but not proceduralized these declarative rules, should succeed with little difficulty.

A second explanation relies on part-list cuing phenomena to explain poor expert performance when given external representations (Lynn Hasher, personal communication). A typical part-list investigation (e.g., Alba & Chattopadhyay, 1985; Anderson, Bjork, & Bjork, 1994; Rundus, 1973; also see Thapar, 1996) finds that some cues act as inhibitors to retrieval. For instance, Anderson et al. (1994) gave subjects categories and exemplars to learn. Some category-exemplar pairs (such as Fruit Orange) received practice while others from those same categories did not. On a recall task cued by category, subjects recalled practiced pairs better than control pairs (from unpracticed categories), but recalled unpracticed pairs worse than control. Part-list retrieval apparently inhibited other list item retrieval. Thus, when provided with an external representation, experts might encounter difficulty accessing other useful representations, and perform poorly. This explanation also resembles research on mental set (e.g., Luchins, 1942; Rees & Israel, 1935). For instance, Rees and Israel (1935) had subjects learn how to reorganize letters into words. Subjects learned a certain serial order. When given "lecam" they learned to produce "camel", and when tested on "pache" they repeated the serial order, producing "cheap". On this test subjects did not produce the more common "peach", suggesting they encountered mental set. Thus, experts might learn a strategy for using a provided representation, failing to use better strategies for that representation. As partial evidence, Frensch and Sternberg (1989) argue that experts' proceduralization of knowledge limits adaptability to new task demands. For alternative representations, expert performance would decline from textual to spatial, perhaps because experts so often encounter textual representations of domain information that novel spatial representations could not be as easily used; novices, though, should have no difficulty using spatial representations.

In sum, four outcomes predict different patterns of results for experts, holding novice performance steady at moderate enhancement, when investigations provide subjects with external representations. Experts can show an additive, adverse, or no effect compared to novices, or simply the same effect as novices. To anticipate the literature review next, prior research has found instances of all of these outcomes.

Existing Findings

Few investigations have explicitly studied the interaction between experience and external representation. Those that do support all four possible effects of experience on representation. Each is described.

Same Effect. The majority of investigations of expertise support the Same Effect. Whenever experts and novices are presented with information, and experts outperform novices by a consistent margin, the external representation of that information has the same effect on experts as novices. For instance, Schneider, Gruber, Gold, and Opwis (1993) found experts to be superior to novices in reconstruction of random chess board patterns. Even on a control board, which differed in shape and color, experts learned to reconstruct faster than novices over five trials. Similarly, Gentner (1988, pp. 14-16) cites an investigation in which expert and novice typists typed letter strings. Both groups slowed down from words to pseudo-words to non-words, but experts typed faster than novices on all strings. Also, Norman et al. (1989, experiment 1) presented normal and scrambled medical patient protocols to subjects of varying clinical expertise. While amount of information recalled from scrambled protocols held steady, recall from normal protocols increased with expertise. Additionally, Halpern and Bower (1982, experiment 2) had musicians and non-musicians recall good, bad and random ten-note melodies. Though melody type interacted with experience, musicians outperformed non-musicians on all melodies, including random melodies.

Additive Effect. Some investigations find support for the Additive Effect, where representation helps experts more than novices. For instance, Vicente (1992) presented process control simulations to expert engineering and novice non-engineering graduate students. Subjects viewed each simulation and estimated final process variable values. Vicente began each simulation in a meaningful, fault, or random state, and also presented a full or reduced display. Experts estimated final values more accurately than novices, and could compensate for reduced displays for meaningful initial values. These results indicate experts induced process constraints from these representations, improving their performance. Novices could induce very few process constraints from the representation. Similarly, Egan and Schwartz (1979) found that electronics experts recalled more from a circuit diagram than novices, though only for meaningful diagrams and not randomly arranged diagrams.

Several consumer decision-making studies lend support. For instance, Diamond (1992) discovered that heavy (i.e., experienced) coupon users form complex strategies in an attempt to lower expenditures, while light coupon users tend to rapidly accept or reject promotions. These findings suggest potentially large benefits for experts but moderate benefits for novices. Similarly, Verplanken and Weenig (1993), using graphic versus standard refrigerator energy labels, found an interaction between time pressure and label format. Specifically, under no time pressure (admittedly a very rough approximation to expertise), graphic labels led to more energy efficient choices than standard labels, whereas under time pressure neither representation did so. Also, Goodman (1994) presented subjects with no prior information, or else with information that was either relevant (a substitute for expertise) or irrelevant to recall of paint information contained in alternative representations, and found an interaction between expertise and type of representation. Subjects who saw a matrix were unaffected by given information, whereas subjects who saw a list were assisted by relevant information.

Null Effect. Some investigations find support for the Null Effect. For instance, Levy et al. (1992) assessed food product nutrition label format. One minor finding concerns demographic effects. They noted that gender and extent of nutrition label reading substitute for familiarity, and found no apparent familiarity effect. Similarly, Moorman (1990) manipulated consequence information and reference information on nutrition labels for subjects of varying nutrition familiarity and motivation. Familiarity produced no improvement in nutrition information acquisition and did not interact with format manipulations. Also, Mayer and Gallini (1990) found that novice performance improved on problem-solving tasks when given a dynamic illustration labeling a device's parts and showing its action. Novice performance given a static illustration and expert problem-solving performance across all representations did not improve. Additionally, Lockhead and Crist (1980) have shown that novice readers gain from serifs and other distinguishing alphabetic character features, including features not normally found on these characters. These features, though, should have little and brief (if any) effect on expert readers.

Recent investigations lend further support. For instance, Day (in preparation) studied a problem-solving task using computer chips. Novice computer engineers and an expert electrical engineering researcher deduced, from given input, the output for five alternative chip representations. Alternative representations affected novices' deduction of chip function (measured by response time), but not the expert's deduction, whose response times remained constant across all representations. Similarly, Day also describes a perceptual task in which subjects judged conformations of an organic molecule as same or different. The molecule was represented in a photograph or in one of two textbook formats, Newman or sawhorse line drawings. Undergraduate students with one non-organic chemistry course served as novices; chemistry professors served as experts. Representational format dramatically affected novice perceptual accuracy but failed to affect expert judgments.

Miller and Stigler (1991) describe an interesting, relevant experiment involving internal representation. They make two different predictions about effects of expertise on representation. According to one view, expertise is "a matter of accommodating to or getting deeply into some domain" (p. 32). According to the other view, "experts have worked their way out of the constraints that may be peculiar to a particular skill" (p. 32). Miller and Stigler chose to study abacus users, believing that abacus experts would either represent numbers using features emphasized in abacus procedures ("conceptual determination"), or else abacus experts would represent numbers no differently from abacus novices or naive subjects ("conceptual transparency"). Miller and Stigler collected, from such subjects, number-pair similarity judgments presented either as Hindu-Arabic symbols or as abacus figures. Naive subjects, with no abacus procedural knowledge, judged abacus figures on appearance. Abacus experts treated both representations as if they shared structural information. These findings suggest conceptual transparency of experts, supporting the lack of effect of representation on experience.

Adverse Effect. Some recent investigations find support for the counterintuitive Adverse Effect, in which external representations assist novices but adversely affect experts. For instance, Day (1992) showed dancers brief dance sequences either with words to name each movement or without, then tested for movement reconstruction (that is, they performed the sequences). Preliminary results indicate that presence of words assists novice dancers, whereas presence of words adversely affects proficient dancers. Similarly, van der Veer (1989, experiment 2) presented mathematically oriented and non-mathematically oriented subjects with a simple programming language to solve math problems. Without provision of a graphic problem representation, non-mathematical subjects required more time than mathematical subjects. However, given a graphic representation, non-mathematical subjects required less time while mathematical subjects required less time but made more errors.

Experts employ strategies in using information from a given display (Bédard & Chi, 1992; Chase & Simon, 1973). Requiring experts to use a different strategy (e.g., in retrieving information from mental retrieval structures with which they are unfamiliar) might hurt their performance. In contrast, providing novices with a strategy would assist performance since novices have not yet formed useful retrieval structures (Ericsson & Kintsch, 1995).

In sum, support for all four effects shown in Figures 4-1 & 4-2 above emerges from the very few investigations studying the interaction between expertise and external representation. No investigation supporting any other effect (e.g., external representations assisting expert performance while adversely affecting, or even having no effect on, novice performance) appeared in the literature search. Presumably, then, the figures show all actual outcomes. Experiments 4-1 & 4-2 examined these effects for side-effects information.

Experiment 4-1 · Experienced Subjects

Experiment 4-1 used the same conditions as Experiment 2-1. In Experiment 4-1, however, individuals with medication side-effects experience served as subjects. The desired groups included pharmacy students, medical students, nursing students, practicing pharmacists, practicing doctors of various specialties, and practicing nurses. The student/practicing difference was desired to determine how use of representation changes over level of experience. However, only students were available. The pharmacy/medicine/nursing difference was desired to determine whether or not different types of expertise within the medical domain differentially affect performance. Both pharmacy and medical students were available, and participated.

Method

Subjects. A total of 90 subjects participated: From the University of North Carolina School of Pharmacy, 50 third-year students; from the Duke University Medical School, 40 first-year students. All subjects from each source were run in large group sessions during spring semester. Data from Experiment 2-1 subjects in all four baseline conditions were used for comparison. Details of number of participants per condition are given in a table below.

Materials and Procedures. The materials and procedures for Experiment 4-1 were identical to those of Experiment 2-1, with one exception. Instead of being told that they should envision themselves as patients taking Drug X, these subjects were told that they should envision themselves as doctors prescribing (for medical students) or pharmacists dispensing (for pharmacy students) Drug X.

Expected Results

Two predictions were made. First, these intermediate subjects were expected to outperform novice subjects; that is, overall accuracy was expected to increase. Second, study representation was not expected to affect intermediate performance as greatly as it did novice performance. That is, experience was expected to attenuate the baseline representation results; the Null Effect was predicted. Reasoning for these predictions follows.

Experiment 4-1 used subjects with greater and more professional experience with medication side-effects than subjects of Experiment 2-1. Experienced subjects have been found to agree with each other on domain organization (Cooke & Schvaneveldt, 1988; Murphy & Wright, 1984), thus are expected to be able to re-represent internal representations into those with which they are accustomed (see Jones & Schkade, 1995; see also Carroll et al., 1980). There should be little difference, then, whether information is presented textually or spatially, especially for practicing subjects, potentially for these intermediate subjects. Since they have not yet attained expertise, there might remain a small, beneficial effect of spatial over textual representations for intermediate subjects, but the increase should be less than that for novices.

Still, experience has also been found to improve performance: Experts outperform novices regularly on memory tasks (Chase & Simon, 1973; Chiesi et al., 1979; Egan & Schwartz, 1979; Halpern & Bower, 1982; McGraw & Pinney, 1990; Myles-Worsley et al., 1988; Norman et al., 1989, experiment 1; Schneider et al., 1993). Prior experience with side-effects information should enable intermediate subjects to incorporate information about Drug X more quickly and efficiently than novice subjects (cf. Bédard & Chi, 1992). Thus, Experiment 4-1 was predicted to show increased overall accuracy relative to novice performance, but less so for spatial representations than for textual representations.

Results and Discussion

Figure 4-3 plots results of Experiment 4-1; Table 4-1 tabulates results. For medical students, an analysis of variance demonstrated at least one significant difference among the accuracy means across representations ($F_{3,36}=4.69$, $p<.007$). Planned contrasts demonstrated an advantage in memory performance for subjects who received spatial representations over subjects who textual representations ($F_{1,36}=11.40$, $p<.002$). However, t-tests revealed that the only significant performance difference was between the Tree diagram and Paragraph conditions. For pharmacy students, an analysis of variance just failed to demonstrate differences among accuracy means across study conditions ($F_{3,46}$=2.69, ***p***<.06). While a planned contrast demonstrated an advantage in memory performance for subjects who received spatial representations over subjects who received textual representations ($F_{1,46}$=7.63, ***p***<.008), t-tests showed performance in all four conditions as essentially equal.

Table 4-1
Experiment 4-1 Results
Experienced Subjects

Subject Source	Study Rep.	N	Overall Accuracy (%)	Std. Error (%)
Med. Students	Paragraph	9	47.4	4.0
	Outline	10	55.4	5.6
	Tree	10	68.2	3.7
	Matrix	11	61.7	2.3
Pharm. Students	Paragraph	12	46.1	3.0
	Outline	12	47.3	3.8
	Tree	13	57.4	2.5
	Matrix	13	54.5	3.9

These data were then combined with novice data to examine any effect of experience on memory performance. A 4x3 analysis of variance (study representation by novice, pharmacy, or medical experience) found significant effects of representation ($F_{3,176}$=15.25, ***p***<.0001) and experience ($F_{2,176}$=3.35,

p<.04), but not their interaction ($F_{6,176}$<1). Representation yielded results that mirrored baseline results. Medical students performed significantly better than novices by a t-test, yet, interestingly, novices and pharmacy students did not differ from each other. The lack of interaction suggests that, despite slightly different performance patterns across study conditions by these groups, alternative representations affected subjects similarly regardless of experience.

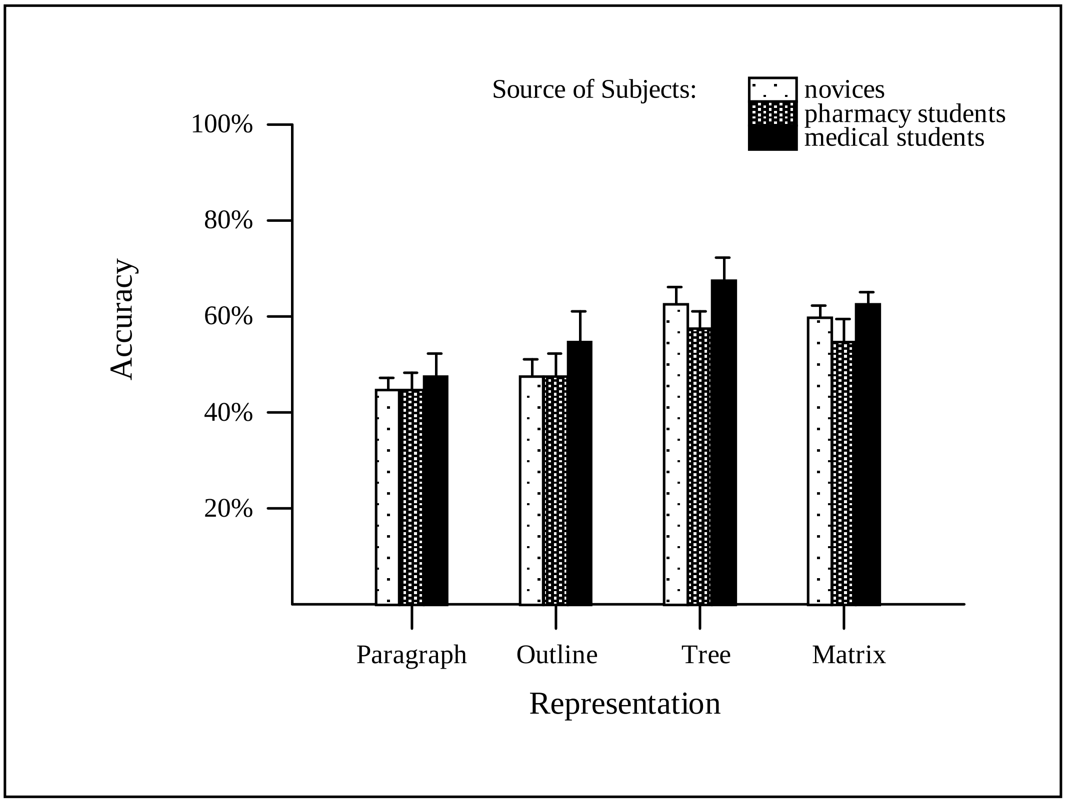

Figure 4-3
Experiment 4-1 Results
Experienced Subjects

Experiment 4-1 thus replicated the baseline pattern of results, but lent only partial support to two predictions. One group of intermediate subjects (but only one of two groups) outperformed novice subjects on the memory task. Both groups of intermediate subjects demonstrated slightly but not significantly different patterns of results across study conditions, compared to novices. To extend these results, and to determine if selective interference occurs in experienced subjects, Experiment 4-2 tested intermediate subjects using the alternative representations filler task.

Experiment 4-2 · Experienced Subjects and Selective Interference

According to reasoning given in Chapter 3, for paragraph and outline study representations, retrieval from LT-WM uses propositional structures kept in ST-WM, whereas for tree and matrix study representations, retrieval uses imagistic structures (perhaps in addition to propositional structures). These images were expected to assist novices on a memory task. However, experience was expected to attenuate the effect of study representation. Intermediate subjects of Experiment 4-1 were expected to have had experience with side-effects information, especially that presented in textual form. They were thus expected to perform nearly as well in textual conditions as in spatial conditions. Experiment 4-1 only partially supported this prediction.

The baseline filler task, however, required subjects to answer medication side-effects questions, which might have adversely affected experienced subjects more than novices. Experience leads to change in the structure of knowledge, with areas of knowledge gaining both organization and refinement (Cooke & Schvaneveldt, 1988; Murphy & Wright, 1984). Recall of study information by intermediate subjects, then, might have been affected by filler questions that they saw as related to the information. Recall by novices might have been unaffected by the same questions because novices, with less side-effects experience, saw the questions as unrelated to study information.

Experiment 4-2 used a different filler task, the food nutrition task described in Experiment 3-2. This task required processing of information unrelated to side-effects; the prediction was made, then, that intermediate performance should increase. The further prediction was made that, in contrast to novices, experienced subjects should not experience selective interference, for two reasons. First, because experienced subjects might re-represent given information into a retrieval structure not necessarily resembling the given study representation (Jones & Schkade, 1995), there should be less opportunity for interference between matching imagistic representations. Second, because the filler task should no longer interfere as strongly with study information, intermediate subjects might remember the information well in both textual conditions (with which they have experience) and spatial conditions (which generally assist performance). Expected results for Experiment 4-2, then, remain unchanged from expected results for Experiment 4-1: Experience was expected to attenuate effects of study representation.

Method

Subjects. A total of 111 subjects participated: From the University of North Carolina School of Pharmacy, 84 third-year students; from the Duke University Medical School, 27 first-year students. All subjects from each source were run in large group sessions during spring semester. Data from Experiments 3-2 & 4-1 subjects were used for comparison. Details of number of participants per condition are given in a table below.

Materials and Procedures. The materials and procedures for Experiment 4-2 were identical to those of Experiment 3-2, with the sole exception noted in procedures for Experiment 4-1.

Results and Discussion

Figure 4-4 plots results of Experiment 4-2; Table 4-2 tabulates results.[15] An analysis of variance found no difference in performance between pharmacy and medical students ($F_{1,109}<1$), hence both displays combine their data. For combined data, a test of potential selective interference effects found that neither filler task ($F_{3,99}<1$) nor its interaction with study representation ($F_{5,99}<1$) was significant. Medical student and pharmacy student data were then analyzed separately to test study representation effects. For medical students, an analysis of variance demonstrated at least one significant difference among the accuracy means across representations ($F_{3,23}=3.52$, $p<.03$). Planned contrasts demonstrated an advantage in memory performance for subjects who received spatial representations over subjects who received textual representations ($F_{1,23}=5.05$, $p<.03$). However, with this small sample of subjects, t-tests revealed no significant performance differences across study conditions. For pharmacy students, an analysis of variance demonstrated at least one significant difference among accuracy means across study conditions ($F_{3,80}=4.58$, $p<.005$). A planned contrast demonstrated an advantage in memory performance for subjects who received spatial representations over subjects who received textual representations ($F_{1,80}=6.76$, $p<.01$), while a t-test showed a performance difference only between the Matrix and Paragraph conditions.

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[15]. Due to low numbers of available subjects, the same three conditions as in Experiment 3-2 were omitted. Also, two outline filler conditions (Tree-Outline and Matrix-Outline) were given low priority for similar reasons, hence were filled by only two and no subjects, respectively.

Intermediate subject data were combined with novice data from Experiments 2-1 & 3-2 in a 2x3x4 analysis of variance to examine any effect of

Table 4-2
Experiment 4-2 Results
Experienced Subjects and Selective Interference
(intermediate groups combined)

Study-Filler Reps.	N	Overall Accuracy (%)	Std. Error (%)
Paragraph-Paragraph	11	42.7	2.8
Paragraph-Outline	9	47.0	4.0
Paragraph-Tree	11	46.1	4.4
Paragraph-Matrix	10	48.8	4.6
Outline-Paragraph		(not done)	
Outline-Outline	9	51.2	4.1
Outline-Tree		(not done)	
Outline-Matrix		(not done)	
Tree-Paragraph	11	54.4	6.1
Tree-Outline	2	58.0	2.7
Tree-Tree	11	59.7	5.0
Tree-Matrix	10	60.4	5.2
Matrix-Paragraph	9	63.1	3.8
Matrix-Outline		(not done)	
Matrix-Tree	10	57.0	4.9
Matrix-Matrix	8	64.5	4.4

experiment (baseline vs. food nutrition filler task), experience (novice, pharmacy student, or medical student), or study representation on memory performance and selective interference. Specific contrasts revealed study representation as the only significant effect ($F_{3,358}$=26.12, p<.0001), although experience approached significance ($F_{2,358}$=2.31, p<.10), with medical students performing best. No other main effect or interaction came close to

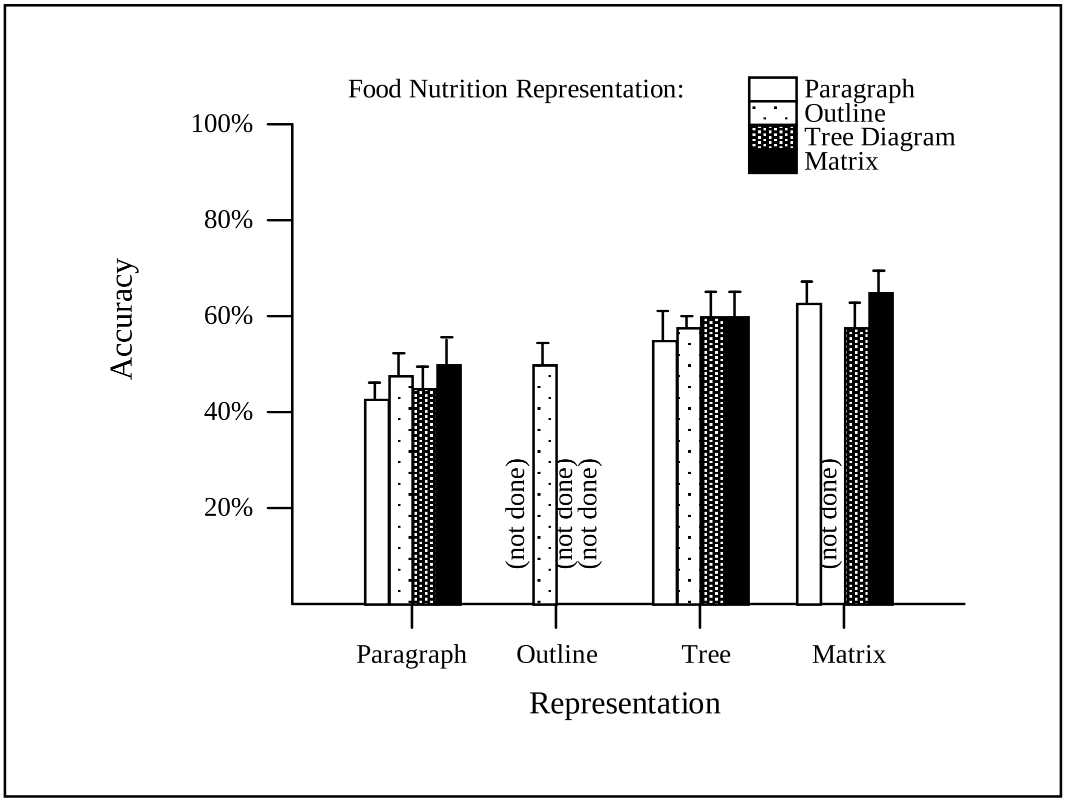

Figure 4-4
Experiment 4-2 Results
Experienced Subjects and Selective Interference
(intermediate groups combined)

significance (all $F<1$). In all analyses, performance for both intermediate groups resembled the baseline pattern of novices, with subjects in spatial study conditions outperforming subjects in textual study conditions.

Experiment 4-2 thus, as predicted, found no effect of selective interference on intermediate subject performance, but did not quite, as expected, find a benefit of experience. As in Experiment 4-1, both groups of intermediate subjects demonstrated slightly but not significantly different patterns of results across study conditions, compared to novices, but level of performance equalled that of novices.

General Discussion

Experience had little effect on results of Experiments 4-1 & 4-2, aside from medical (but not pharmacy) students barely outperforming novices, and both intermediate groups exhibiting slightly different patterns of results across study conditions. Regardless of filler task, too, performance in spatial conditions exceeded that of textual conditions. These results might be understood by considering task demands and the nature of representation of knowledge by these subjects.

Task Demands

Previous research has found that experts usually, but not always, outperform novices. When experts cannot demonstrate perceptual advantages, or when task demands favor non-standard responses, experts generally have trouble. For instance, investigators propose a perceptual or pattern-matching ability difference between experts and novices on information within the domain of expertise (Chase & Simon, 1973; Chiesi et al., 1979; Halpern & Bower, 1982; Myles-Worsley et al., 1988; Schneider et al., 1993; Shanteau, 1988). However, a cost of expertise (Bédard & Chi, 1992; Frensch & Sternberg, 1989), wherein expert performance suffers relative to novice performance, occurs when an expert is prevented from employing this enhanced perceptual ability, or where context limits its usefulness (Chase & Simon, 1973; Norman et al., 1989). Similarly, tasks that require atypical processing, such as those that require superficial, not structural, processing, affect experts more than they affect novices (Adelson, 1984; Arkes & Freedman, 1984; Fiske, Kinder, & Larter, 1983).

All subjects in the current research performed a memory task. However, subjects in a related experiment (see Carrero, 1995) performed an inference task, studying this same medication side-effects information, performing the baseline filler task, yet responding for each side-effect, not with an action to take, but with a description of severity ("life-threatening", "dangerous", "troublesome", "bothersome", "inconsequential"). Subjects therefore had to infer severity descriptions from actions given.[16] Different groups of pharmacy students from the University of North Carolina (n=65) and Duke undergraduate students (n=80) than those who participated in Experiments 4-1 & 4-2 served as intermediate and novice subjects. In contrast to Experiments 4-1 & 4-2 memory results, experienced subject inference responses in this related experiment were consistently higher than novice responses ($F_{1,137}$=5.41, p<.02), but study representation played no role ($F_{3,137}$<1). Therefore, the pattern of results across study conditions reflected task demands (see also Patel & Groen, 1991; Johnson & Russo, 1984).

What demands, then, were placed on intermediate subjects in Experiments 4-1 & 4-2 that did not allow their experience to assist performance relative to novices? First, because information was given for a fictitious drug, pharmacy and medical students could not readily incorporate it into existing knowledge structures. This point is addressed below. Second, the procedure of study/filler/test might have been novel to intermediate subjects; most novices,

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16. Actually, some subjects did respond with actions different from those studied. However, these actions ("rush to the emergency room", "call doctor immediately", "tell doctor at next visit", "continue to monitor symptoms", "ignore symptoms") are rated in concurrent studies by Day and Hubal as equivalent in level of severity to the descriptive terms, hence an inference was still required.

taking or having taken undergraduate psychology courses, would have been familiar with this procedure. Both filler tasks affected results evenly, but intermediate subjects might have been more distracted than novices.[17] Third, strong effects of study representation might have precluded effects of experience. Prior research and Experiment 2-1 baseline results have demonstrated consistent advantages of spatial representations over textual representations; this effect may have assisted novice subjects given spatial representations to act like experienced subjects but adversely affected experienced subjects given textual representations to act like novices. In contrast, subjects in the related inference experiment did not need to recall study information, since side-effects were assigned to typical severity levels (see Byerly, 1996). Instead, regardless of study representation, they could rely on prior knowledge.

Knowledge Representation

Experts impose organization on given information that novices cannot. For instance, Hassebrock et al. (1993), using patient protocol sheets, found that, after a delay, novices recalled information in its original format, whereas experts recalled mainly diagnostic information. Their findings suggest novices and experts differ in internal representation. Similarly, Lynch, Chakravarti, and Mitra (1991), investigating contrast effects on consumer product ratings, found

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[17]. A related argument proposes motivational differences between novices and intermediate subjects. That is, intermediate subjects might have been less motivated to perform well either because they felt they already knew such material and required less effort to remember it (Alba & Hutchinson, 1987, p. 439), or because the filler task caused adverse affect. However, motivational differences are normally found for experts, not intermediate subjects (e.g., Bettman & Park, 1980). Also, subjects in these experiments were observed to be consistently motivated to perform well.

that such effects actually change novice internal representation but only affect how experts interpret response scale anchors. Hatano and Osawa (1983) investigated abacus experts' internal representations, and found that experts represent digits, but not letters or other verbal items, in a visuo-spatial image (see also Boster & Johnson, 1989; Cooke & Schvaneveldt, 1988). Chi et al. (1981) claim that expert/novice differences in representation stem from poorly formed, qualitatively different, or missing category knowledge in novice subjects. Thus, experts and novices represent knowledge internally differently, leading to differences in the use of external knowledge as well. Experts, having greater familiarity and knowledge, require less effort in using external information (cf. Bettman, 1979, chapter 5).

A few tenuous findings in Experiments 4-1 & 4-2 point to differences in knowledge representation between types of expertise, here student doctors and pharmacists, which some investigators find (e.g., Patel & Groen, 1991; Schraagen, 1993; Schvaneveldt et al., 1985; Smith, 1990; Weiser & Shertz, 1983). For instance, Smith (1990) found that biology faculty categorized genetics problems differently than genetics counselors. Similarly, Weiser and Shertz (1983) found that experienced computer programmers categorized programs differently than programming managers. On the current memory task, medical students slightly outperformed pharmacy students, perhaps because they were able to incorporate this information more easily into existing knowledge.

However, the experienced subject groups in Experiments 4-1 & 4-2 generally did not perform differently from each other or from novices, and therefore did not demonstrate different representation of knowledge. Two reasons for this finding could be that pharmacy and medical students have not attained expertise, or that they were unable to demonstrate their knowledge.

Although, indeed, these intermediate subjects are no experts, they do have greater knowledge than novices about medications and side-effects. The related inference experiment described above demonstrated this, as have numerous studies in which intermediate subjects outperform novice subjects (e.g., Chase & Simon, 1973; Chi et al., 1981; Cooke & Schvaneveldt, 1988; Hanisch et al., 1991; Hassebrock et al., 1993; Miller & Stigler, 1991; Murphy & Wright, 1984; Myles-Worsley et al., 1988; Norman et al., 1989; Patel & Groen, 1991; Silver, 1981; Weiser & Shertz, 1983). Thus, a distinction between experience and expertise cannot fully account for findings.

These experienced subjects, however, did not demonstrate an advantage of their experience. The side-effects information for Drug X, therefore, was not fully incorporated into existing knowledge. It is likely that information for a fictitious drug requires considerably longer than three minutes to be fully integrated into general side-effects knowledge, yet all subjects were allowed only this length of time for study. Furthermore, no additional information, beyond severity and frequency, was given in study materials; no other details for the drug (e.g., chemistry, dosage, usage instructions) were described. Pharmacists and doctors do not learn about severity and frequency of side-effects of new drugs in isolation from these other drug details. Thus, this information, though carefully constructed, may have failed to achieve complete ecological validity with experienced subjects.

Summary

In sum, task demands and knowledge representation help account for findings from Experiments 4-1 & 4-2. Because experienced subjects could not use their knowledge to advantage on this memory task, study representation alone affected results, and results supported the Same Effect (i.e., similar effects of textual vs. spatial alternative representations for experts and novices). Findings from experiments in this chapter are revisited in the final chapter.

Chapter 5. Process Model

A process model outlined in Chapter 3 describes mental processing that takes place when accessing information in alternative representations. Spatial representations generally, but not always, assist information access by providing cues, or indices, into specific regions of the display. Mental images, which the imagery hypothesis suggests result from studying these displays, assist information access equivalently to the displays. Textual representations generally provide few cues into specific regions of the display.[18] Propositional representations (e.g., Anderson, 1983; Kintsch, 1988) that result from studying textual displays also provide little assistance in accessing information. This chapter describes an experiment to further test this process model, then elaborates on predictions made by the model.

Experiment 5-1 · Representation Transposition

Effect of Transposition of Representations

According to the process model, tree diagrams and matrices prioritize dimensions differently. In particular, for this side-effects study information, a tree diagram prioritizes that dimension which branches from the root, whereas a

[18]. Cues can be incorporated into textual representations, for instance, by highlighting regions using italics, color, font changes, etc. Similarly, text can be organized, or chunked, into distinguishable regions. Notice, however, that these types of organization introduce imagistic (i.e., visual or spatial; Watson, 1994) information into the display.

matrix assigns equal priority to both dimensions. That is, to access a specific side-effect in the tree, specific paths within first one dimension then the second must be followed. In contrast, to access a specific side-effect in the matrix, a path may be chosen with either dimension first and the other second. Textual representations such as paragraph and outline, meanwhile, make dimension priority difficult to assess without considerably more effort than in spatial representations.

The baseline Experiment 2-1 demonstrated similar performance for Tree and Matrix conditions. The process model, however, suggests an interesting manipulation that should lead to differential performance: Transpose the location of study information, with severity information replacing frequency information and vice versa. According to the process model, transposition should affect which underlying dimension a tree diagram prioritizes, but not a matrix, nor for either non-spatial representation. According to the imagery hypothesis, transposition should affect the use of imagistic representations as well as external representations. Experiment 5-1 tests these predictions.

Method

Subjects. Experiment 5-1 used 141 Duke University students, including data from Experiments 2-1 & 2-2 subjects used for comparison. Details of numbers of participants per condition are given in tables below.

Materials. Every subject was handed a booklet of four pages. The first page for all subjects was again a colored title page hiding the study page from view. The second through fourth pages contained, respectively, the side-effects information to be studied, a filler task, and a response sheet for the memory test. Differences on these final three pages from the three pages in the baseline experiment are described in turn.

Study Representation. For Experiment 5-1, two paragraph representations, two tree diagrams and two matrix representations were used.[19] One each of the Paragraph, Tree and Matrix were exactly those used originally in Experiment 2-1. The other of each representation was transposed. Specifically, in the Transposed Paragraph representation (Figure A-9), the first sentence still listed four side-effects but provided no severity or frequency information, as in the Original Paragraph representation. However, each of three subsequent sentences stated a description of frequency, four descriptions of severity, and two specific side-effects for each severity term under that frequency term, whereas originally four subsequent sentences stated a description of severity and three descriptions of frequency within. In the Transposed Tree diagram (Figure A-10) three lines descended from its root "Drug X", each branch representing a level of frequency, whereas in the Original Tree diagram each of these branches represented a level of severity. Beneath each branch four nodes indicated four levels of severity, whereas originally three nodes indicated three levels of frequency. Each of 12 resulting nodes still listed two side-effects, and a single detached node remained near the bottom of the page listing four side-effects for which no severity or frequency information was given. In the Transposed Matrix representation (Figure A-11) there were three levels of frequency along its left, vertical axis, and four levels of severity along its top, horizontal axis. Each of the 12 resulting cells still listed two side-effects. An additional thirteenth cell, marked by two question marks indicating no

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[19]. An outline representation was omitted for practical reasons similar to those described in Experiment 3-2: Even though outlines add hierarchical structure to paragraphs, performance did not differ between these two textual conditions in the baseline or subsequent experiments.

information for either severity or frequency, still listed four side-effects.

Filler Task. For Experiment 5-1 the filler task was exactly that used in Experiment 2-1.

Response Sheet. For Experiment 5-1, four response sheets were used. One response sheet was exactly that used in Experiment 2-1, and one was exactly that used in Experiment 2-2 for subjects who were tested on response order. The third and fourth response sheets had single modifications: Subjects entered either only a severity response (Figure C-3) or only a frequency response (Figure C-4) for each side-effect in the sole blank of the modified response sheets, whereas they entered both severity and frequency responses for each side-effect in the original two response sheets. These single-response sheets were included to ensure that it is study representation dimension prioritization that affects recall of specific dimension information, regardless of which dimension the response task might prioritize (severity or frequency or neither). Subjects still completed blanks by entering a single number ranging from 0 through 4 for severity or a single number ranging from 0 through 3 for frequency.

Procedure. Experiment 5-1 followed the exact same procedures as Experiment 2-1.

Expected Results

The process model leads to the following expected results for transposed representations, where severity and frequency information change place. According to models of reading comprehension (e.g., Kintsch, 1988), transposition should have little effect on propositional structures derived from textual study representations, hence memory performance in the Transposed

Paragraph condition should be comparable to Original Paragraph baseline performance. Similarly, since matrices make dimensions (i.e., severity and frequency) equally accessible, transposition should have little effect, hence memory performance for the Transposed Matrix condition should be comparable to performance for the Original Matrix condition. However, a tree diagram allows easier access to its most prominent dimension, that branching from its root. The Transposed Tree prioritized frequency information whereas the Original tree prioritized severity information, hence performance in these two conditions for the two dimensions should differ. Specifically, the Transposed Tree representation should assist frequency memory performance, while the Original Tree representation should assist severity memory performance.

These predictions also support the imagery hypothesis. Neither spatial representation, Tree or Matrix, appears to have greater organization; they are simply organized differently, so the organization hypothesis provides no prediction for this transposition manipulation. However, the imagery hypothesis provides a clear prediction, since spatial representations presumably lead to analogous imagistic representations. The type of access afforded is different between tree diagrams and matrices, whether external or imagistic; differences in dimension prioritization should lead to differential performance between original and transposed conditions for tree diagrams but not for matrices.

Results and Discussion

An analysis of variance found no difference among the four response sheets ($F_{3,137}$=1.62, ***ns.***; see Table 5-1). Subject responses were therefore collapsed over response sheets and then separated into severity and frequency accuracies.[20] Figure 5-1 shows results of Experiment 5-1; Table 5-2 tabulates results. A 2x2x3 analysis of variance examined effects of type of representation (Original vs. Transposed), type of response (severity vs. frequency), and study representation (Paragraph vs. Tree vs. Matrix) on memory performance. As expected, subjects in Tree and Matrix conditions outperformed subjects in Paragraph conditions ($F_{2,209}$=12.90, ***p***<.0001). Transposition alone did not affect performance ($F_{1,209}$<1), nor did any interaction, but planned separate representation analyses revealed the following. For Paragraph, as expected, type of representation and type of response did not interact ($F_{1,62}$=1.22, ***ns.***). For Matrix, too, as expected, type of representation and type of response did not interact ($F_{1,56}$<1). For Tree diagram, though, they did interact ($F_{1,91}$=4.26, ***p***<.04), in the predicted direction. That is, severity accuracy exceeded frequency accuracy for the Original Tree, while frequency accuracy exceeded severity accuracy for the Transposed Tree. These results all support process model and imagery hypothesis predictions.

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20. For subjects who responded with only severity or only frequency information, one value was calculated; for subjects who responded with both severity and frequency, two values were calculated. This led to 221 total observations.

Table 5-1
Experiment 5-1 Results
Response Sheet Analysis

Response Sheet	N	Overall Accuracy (%)	Std. Error (%)
Severity-Frequency	56	56.4	1.9
Frequency-Severity	24	51.9	3.0
Severity-only	31	59.0	2.7
Frequency-only	30	60.0	2.7

Table 5-2
Experiment 5-1 Results
Transposed Representations

Study Rep.	N	Severity Accuracy (%)	Frequency Accuracy (%)	Overall Accuracy (%)	Std. Error (%)
Original Paragraph	28	49.4	40.6	45.0	2.1
Transposed Paragraph	10	47.1	49.3	48.2	2.8
Original Tree	48	66.8	61.0	63.9	1.8
Transposed Tree	25	54.7	63.1	58.7	3.2
Original Matrix	20	60.9	57.3	59.1	1.9
Transposed Matrix	10	59.6	53.2	56.4	3.1

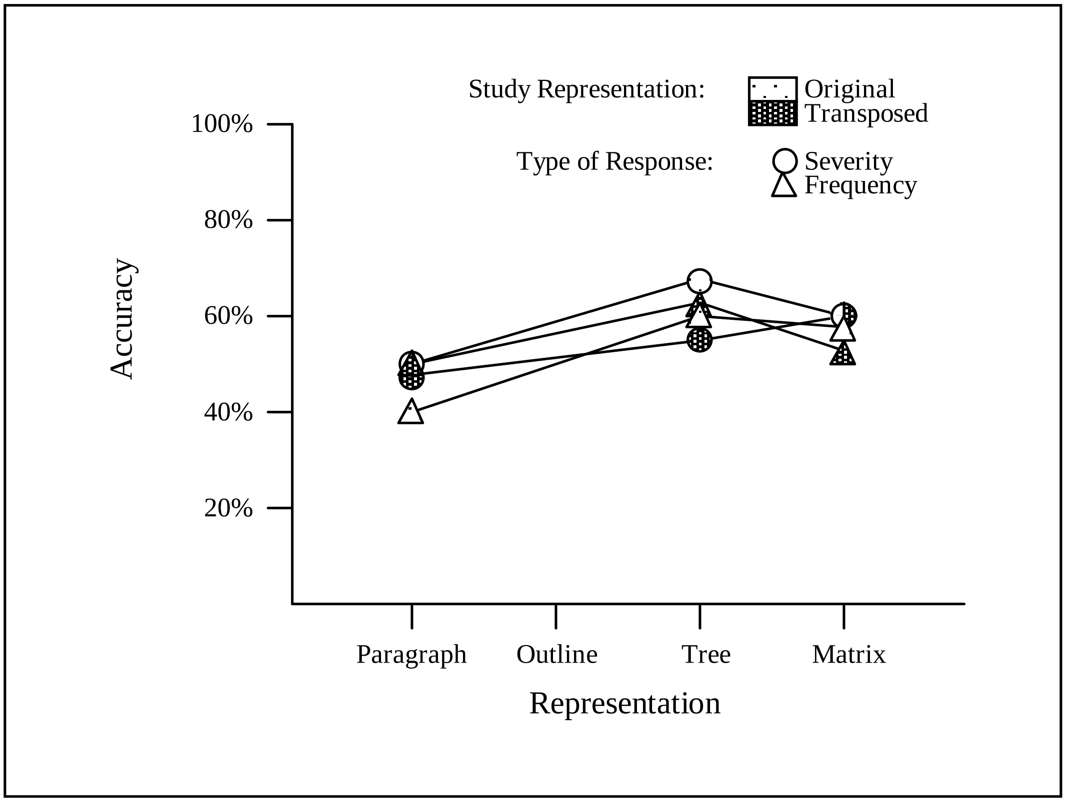

Figure 5-1
Experiment 5-1 Results
Transposed Representations

Process Model Predictions

Experiment 5-1 supported process model predictions. With further minor methodological variations, additional process model predictions could be tested. In particular, both study representation and cognitive task required of subjects might yield processing details.

Cognitive Task

All experiments here employed a cued recall task. Cued recall and recognition tasks enable subjects to retrieve specific information associated with cues. In contrast, free recall and reconstruction (e.g., Chase & Simon, 1973) tasks force subjects to retrieve cues as well as associated items. Meanwhile, categorization tasks, such as sorting and clustering, allow subjects to use underlying dimensions, both those in the study display and those known beforehand (see Byerly, 1996). The process model can predict (e.g., based on clarity and priority of dimensions in the displays) relative performance among alternative representations for these different tasks, as described in Chapter 3.

Specific representations with important dimensions highlighted can then be tailored to needs shaped by the cognitive task, timing, concurrent cognitive load, and the information itself. For instance, time to traverse a representation depends on format (Carroll et al., 1980; Verplanken & Weenig, 1993). Under time constraints demanding easy access to information, formats that enable indexed access to information (e.g., tree diagrams, matrices, paragraphs with immediately obvious highlighted areas; cf. Pylyshyn et al., 1994) suit demands better than other alternative formats. In contrast, under conditions requiring slower elaboration of information with existing knowledge, formats organized by underlying dimensions which conform to prior knowledge suit demands better than other alternative formats. Similarly, on dual tasks where subjects must retain information while concurrently attending to additional presented information (e.g., Baddeley & Hitch, 1974; Brooks, 1968; Shah & Miyake, 1996), the nature of either retained or attended information can affect results. More similar processes required to access information should lead to greater interference with performance on one or both tasks. Thus, the process model suggests "good" alternative representations based on cognitive tasks required of subjects (see also Zhang, 1996).

Study Representation

Alternative representations have different consequences for performance on a given cognitive task (Day, 1988), as results from all current experiments show. Paragraphs, outlines, tree diagrams and matrices are common but certainly not exhaustive of all alternative representations. Some possible alternatives were discussed above. For instance, a fan representation has been shown by Day in concurrent studies to assist performance relative to a paragraph. In contrast, a spiral representation of sentences would be expected to have either no effect or an adverse effect on performance. In general, though, over many tasks, spatial representations will assist performance relative to textual representations, since they use spatial cues to assist access to dimension information.

Process model descriptions of how a specific representation is processed for a given task (e.g., how the display is searched; how items within the display are associated) are easily tested using procedures identical to those of all experiments here. Much previous research has considered processing of textual information (see Ericsson & Kintsch, 1995) or of spatial information (e.g., Johnson, Payne, Schkade, & Bettman, 1991; McGuinness, 1986; Shah & Carpenter, 1995), but little research describes differences in processing across alternative representations. The few that do, however, support process model predictions. For instance, Larkin and Simon (1987) contrast sentences versus diagrams, demonstrating that diagrams assist performance relative to lists for search and recognition tasks, but not inference tasks. Search and recognition require rapid access to cued information, which spatial representations provide; inference requires elaboration, which propositions derived from textual representations provide. Similarly, Schkade and Kleinmuntz (1994) demonstrate how display organization (i.e., format) affects information acquisition. Sequential (i.e., list) displays, but not a matrix, make search across non-prioritized dimensions difficult; organization does not, though, affect evaluation of information, which also requires elaboration. (See also Carswell & Wickens, 1987; Zhang, 1996.) Thus, the alternative representations approach (Day, 1988) can simply and effectively test process model predictions.

Summary

The process model introduced in Chapter 3 describes mental processing that takes place when accessing information in alternative representations. Results of Experiment 5-1 supported process model predictions, as do results from prior research involving alternative representations and several cognitive tasks. Experiment 5-1 also supported imagery hypothesis predictions, though Experiments 3-1, 3-2 & 4-2 did not. These findings are discussed next in Chapter 6.

Chapter 6. Discussion

This final chapter provides an overview of thesis experiments and results, and discusses their importance, exploring implications and applications for use of external representations with subjects varying in level of experience.

Overview

Summary of Results

The current research investigated external representation of side-effects information in seven experiments. Experiment 2-1 established baseline results against which results from all six subsequent experiments were compared. The baseline experiment, and all others, demonstrated superior performance on a cued recall task by subjects in spatial study conditions compared to subjects in textual study conditions.[21]

Experiments 2-2a & 2-2b were run as control experiments. Potentially confounding variables such as dimension labeling, gender, compensation, response order, and item order were all shown not to affect baseline results.

Experiments 3-1 & 3-2 attempted to selectively interfere with performance in spatial conditions. Filler task representations were devised to match the four

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[21]. Indeed, an analysis of variance run on all participating subjects (n=567) demonstrated superior performance in spatial versus textual conditions ($F_{1,563}$=40.86, p<.0001).

study representations; expected results were for decreased performance relative to baseline for matching study and filler conditions but not for mis-matching study and filler conditions. Both experiments failed to demonstrate selective interference.

Expertise and representation, on their own, have been studied extensively; the interaction between them has not. Experiments 4-1 & 4-2 included subjects with intermediate levels of knowledge of medications, expecting to find different patterns of performance across study representations for subjects of differing experience. Both experiments demonstrated only partial support for this prediction.

Experiment 5-1 tested how transposition of stimulus dimension information affects performance for alternative study representations. Locations of severity and frequency side-effects information in the study displays were switched, and severity and frequency responses evaluated. The experiment demonstrated a significant effect of transposition on severity and frequency responses for Tree diagrams but not for Paragraph and Matrix representations, as a model of processing predicted.

Emergent Findings

Several hypotheses were proposed to predict results; they can now be re-examined. First, an organization hypothesis predicted superior performance between textual and spatial study conditions due to an increase in organization of information from textual to spatial. This prediction held. The organization hypothesis also successfully predicted no performance difference between Tree and Matrix conditions. It failed, though, in predicting a performance increase from Paragraph to Outline. Thus, an organized representation will generally assist performance compared to a less organized one, but organization alone cannot explain all results.

Second, an imagery hypothesis predicted different performance between textual and spatial study conditions due to an ability to create and use mental images of spatial but not textual representations. Although filler tasks which were designed to interfere with image use did not interfere, a manipulation of information (i.e., transposing severity and frequency) affected responses differently for tree diagrams than for paragraphs and matrices, as the imagery hypothesis suggested. Also, reanalysis of baseline data showed that position of information within study displays affected memory performance for textual more than spatial representations, as the imagery hypothesis succinctly suggested. Thus, a spatial representation appears to yield an imagistic representation, and both afford equivalent patterns of use.

Third, a process model, based on results from prior research, described ease or difficulty of access to specific cued information in each alternative representation. The process model capably predicted performance differences between textual and spatial representations, between novices and intermediate subjects, and between original and transposed tree diagrams. Thus, individuals search, associate, and retrieve information within alternative displays, using dimensions that are or are not prioritized in the display, in a manner consistent with process model predictions.

In sum, these three hypotheses work together to predict whether or not subjects who study one representation will outperform subjects who study an alternative representation. Organized and easily accessible dimension information that is relevant for a given cognitive task epitomizes a good external representation. If, in addition, the representation might not be present upon needing to access information within it, then one which also leads to an imagistic structure is best.

Limitations

Generalizability of results is limited by the content, task, and representations used. For instance, in the current research side-effects information was presented as facts to be learned. Spatial representations might not yield better recall performance than textual representations for, say, narratives (e.g., Bower & Morrow, 1990): Relationships and themes contained in narratives might not easily be separated into underlying dimensions. Similarly, as noted above, encoding and retrieval of information from alternative representations differs depending on the task required of subjects. Thus, subjects in spatial conditions outperformed subjects in textual conditions on cued recall of side-effects information, but a different pattern of results emerged across representation conditions for comprehension of food nutrition information (i.e., the filler task for Experiments 3-2 & 4-2). The robustness of an effect of alternative representations is demonstrated by all current experiments and by prior research; specific results vary with content, task and formats used, as the process model describes.

Importance of Results

A need for good representation arises routinely, leading to several implications, and applications, of alternative representations research.

Implications

External Representation. Many studies demonstrate what Norman (1993) labels the "power of representation": Inclusion of a diagram assists performance (e.g., Gick, 1985; Kotovsky et al., 1985); organization within a presentation assists performance (e.g., Egan & Schwartz, 1979; Russo et al., 1975; Vicente, 1992); alternative representations differentially assist performance (e.g., Day, 1988; Schkade & Kleinmuntz, 1994), depending on scale of dimensions (Zhang, 1996). The current research has stepped beyond these findings to begin to demonstrate not only what representations assist performance, but also when, and how. The process model suggests intelligent choices of configural form, amount of presented information, and prioritized dimensions that depend on subject experience and task demands.

Imagery. Watson (1994) provides a compelling review of the distinction between object and spatial imagery; they are apparently mediated by separate neurological areas. Experiments related to those of the current research (e.g., compare scanning for specific information within a display for paragraphs, spirals and tree diagrams) might contribute to imagery research. Alternative representations differ both visually and spatially; presumably, reaction time, accuracy, brain-imaging, and other measures can examine differences among imagistic representations. Use of alternative representations controls for information equivalence. Furthermore, the process model can suggest how to equate differences in task demands across representations.

Nature of Expertise. Future research into the interaction between representation and experience would elucidate the nature of expertise. For instance, a delineation of task demands in which external representations assist versus adversely affect expert performance can be compared to novice performance under those demands. Similarly, amount of information and content can be manipulated to determine performance effects on experts versus novices. In addition, information content that is directly versus marginally related to domain of expertise can examine effects of type of expertise and specific and general domain knowledge (Shanteau, 1988). Although much is known about expert performance on memory, problem-solving, and categorization tasks, little is known about representation effects on those tasks, except that additive, null, and adverse effects can occur.

Applications

Other Areas of Psychology. Research involving alternative representations and subjects with varying levels of experience could have implications for educational, occupational, and developmental issues. Bereiter and Scardamalia (1986) argue that education produces experts. Students must overcome the "limitations that their initial forms of knowledge and skill impose on them". One approach is to represent knowledge to be learned in a form conducive to student learning. This careful knowledge representation certainly occurs regularly in classrooms, suggesting an important area to study. For instance, Chi, Hutchinson, and Robin (1989) demonstrated how knowledge representation constrains how and what types of inferences children make about dinosaurs. Similarly, research on student use of self-explanations during learning (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Pressley et al., 1992) considers how knowledge is represented to assist learning. Also, Zeitz and Spoehr (1989) had subjects learn to find errors in a robotic system. They found that initial presentation of system components mattered; subjects in the breadth-first presentation outperformed subjects in the depth-first presentation.

Additionally, during presentation of information (e.g., in a conference proceeding), presenters use handouts, notes, projections, simulations, and other external representations. Audience members vary in degree of expertise, so that presentations geared toward degree of audience expertise assists learning. Thus, implications for research using carefully designed external representations extends beyond cognitive psychology to other areas of psychology concerned with teaching or learning.

Artificial Intelligence. Artificial intelligence might also benefit from research on the interaction between representation and expertise. One area of artificial intelligence deals with expert systems, i.e., specialized programs that mimic expert behavior. Construction of knowledge bases used in expert systems (called knowledge engineering) certainly would benefit by knowing in more detail how experts represent their knowledge. A second area of artificial intelligence is machine learning, which attempts to construct machines capable of gaining and using knowledge through interaction with its environment. Knowledge representation plays a critical role in machine reasoning processes (Winston, 1984). A third area is robotics, which is related to machine learning in that a robot interacts with its environment. A robot normally manipulates external objects through sight, hearing and touch; external representations are such objects. A fourth area is in application of knowledge representation research to design of complex systems, such as aircraft cockpit panels (Roske-Hofstrand & Paap, 1986), business telephone systems (Hanisch et al., 1991), and computer-aided design of effective graphical presentations (Mackinlay, 1986). Thus, carefully designed representations, and knowledge of how they may be used, promise application to artificial intelligence as a field.

Everyday Cognition. Norman (1993) uses the term "everyday cognition" to refer to cognitive tasks that individuals employ in the normal course of events. The current research can address understanding of everyday cognitive processes. Individuals are expert-like at numerous tasks (cf. Ericsson & Smith, 1991). Individuals also encounter representation-like objects continuously. For instance, Russo et al. (1975) studied how unit price lists on supermarket shelves affect consumer decisions. Similarly, numerous investigations (e.g., Burton, Biswas, & Netemeyer, 1994; Levy et al., 1992; Moorman, 1990; Russo et al., 1986) studied how nutrition information on food products affects consumer decisions. Also, Day (1988) studied a bus schedule, medication instructions and word-processor commands. Additionally, a sequence of investigations (e.g., Anzai, 1991; Cooke & Breedin, 1994; Kaiser et al., 1986; McCloskey et al., 1980) studied how individuals naively perceive physics concepts. Finally, medication information is critical: Adverse drug events (e.g., medication side-effects, drug-drug interactions) are highly preventable given good exchange of information (Bates et al., 1995); the format of informed consent documents given to prospective patients leads to differences in understanding of the informed consent material (e.g., Kaufer, Steinberg, & Toney, 1985; Tymchuk et al., 1986). Thus, the current research extends the alternative representations approach into another everyday area where the use of representations can yield important findings on the interaction between experience and representation.

Conclusion

In sum, representation plays a pivotal role in cognitive activity. For as long as cognitive psychologists investigate memory, reasoning, and learning processes they must remain cognizant of effects of both external and internal representation of information. The process model and structural hypotheses presented in this thesis enable investigators to control how they present information to subjects, consider how that information is processed, and better understand their results.

SIDE EFFECTS FOR "DRUG X"

SIDE EFFECTS may include wheeziness, unexplained bruising, tremor, or rash. SIDE EFFECTS THAT SHOULD BE REPORTED TO YOUR DOCTOR IMMEDIATELY include: *More common* chest pain, slurred speech; *Less common* - seizure, swelling of mouth or tongue; *Rare* - shortness of breath, uncontrolled bleeding. OTHER SIDE EFFECTS THAT SHOULD BE REPORTED TO YOUR DOCTOR include: *More common* - blurred vision, dizziness; *Less common* - hallucinations, joint pain; *Rare* - palpitations, tingling. SIDE EFFECTS THAY MAY GO AWAY DURING TREATMENT include: *More common* - anxiety, diarrhea; *Less common* - drowsiness, memory problems. *Rare* - nausea, sleep disturbances. If they continue or are bothersome, report to your doctor. SIDE EFFECTS THAT USUALLY REQUIRE NO MEDICAL ATTENTION include: *More common* - sweating, thirst; *Less common* - vomiting, weakness; *Rare* - headache, muscle aches.

Figure A-1

Baseline Paragraph Study Representation

SIDE EFFECTS FOR "DRUG X"

SIDE EFFECTS may include wheeziness, unexplained bruising, tremor, or rash.

SIDE EFFECTS THAT SHOULD BE REPORTED TO YOUR DOCTOR IMMEDIATELY include:
More common - chest pain, slurred speech;
Less common - seizure, swelling of mouth or tongue;
Rare - shortness of breath, uncontrolled bleeding.

OTHER SIDE EFFECTS THAT SHOULD BE REPORTED TO YOUR DOCTOR include:
More common - blurred vision, dizziness;
Less common - hallucinations, joint pain;
Rare - palpitations, tingling.

SIDE EFFECTS THAT MAY GO AWAY DURING TREATMENT include:
More common - anxiety, diarrhea;
Less common - drowsiness, memory problems;
Rare - nausea, sleep disturbances.
If they continue or are bothersome, report to your doctor.

SIDE EFFECTS THAT USUALLY REQUIRE NO MEDICAL ATTENTION include:
More common - sweating, thirst;
Less common - vomiting, weakness;
Rare - headache, muscle aches.

Figure A-2
Baseline Outline Study Representation

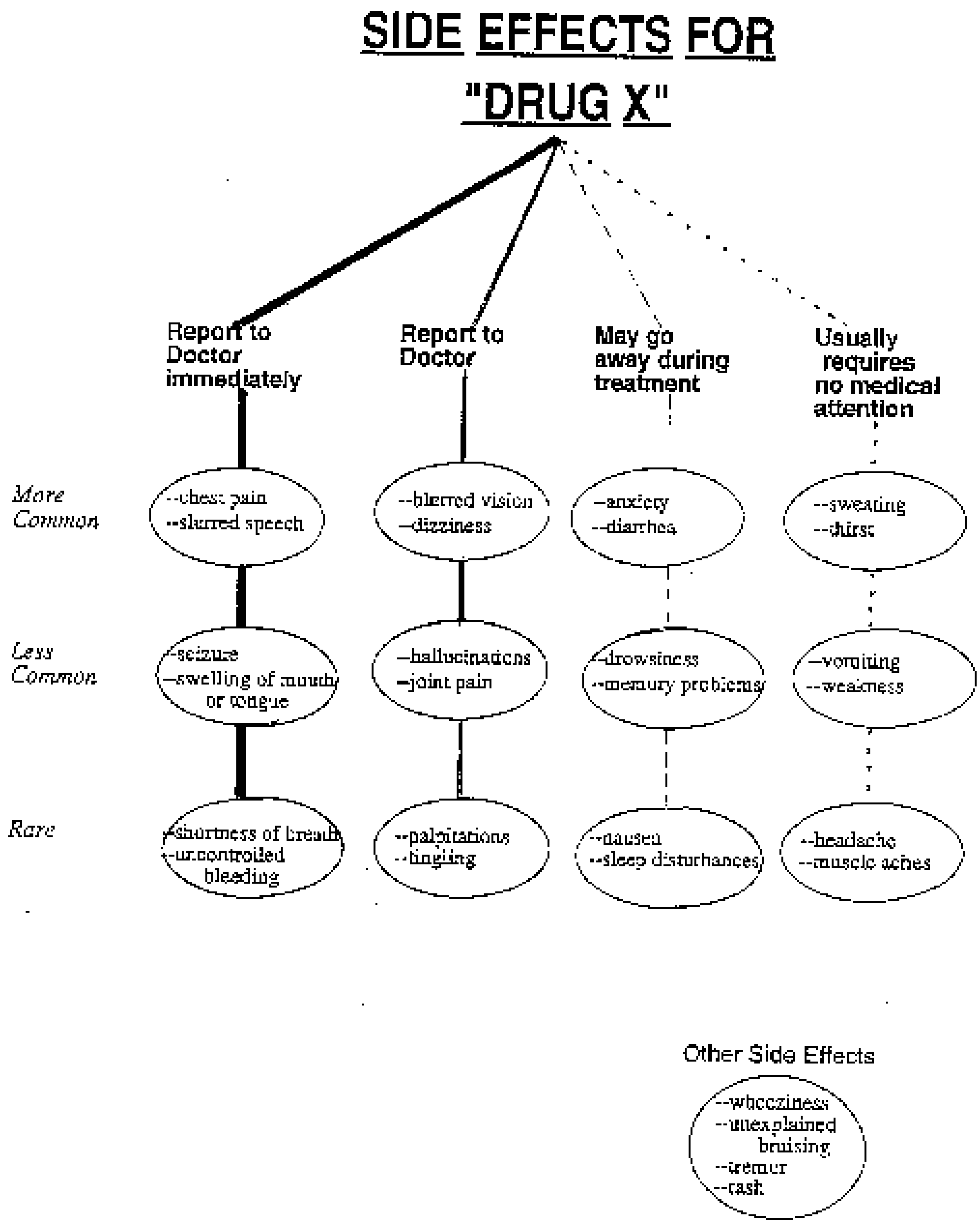


Figure A-3

Baseline Tree Study Representation

SIDE EFFECTS FOR "DRUG X"

FREQUENCY

SEVERITY

	More Common	Less Common	Rare	?
Report to Doctor Immediately	--chest pain --slurred speech	--seizure --swelling of mouth or tongue	--shortness of breath --uncontrolled bleeding	
Report to Doctor	--blurred vision --dizziness	--hallucinations --joint pain	--palpitations --tingling	
May go away during treatment	--anxiety --diarrhea	--drowsiness --memory problems	--nausea --sleep disturbances	
Usually requires no medical attention	--sweating --thirst	--vomiting --weakness	--headache --muscle aches	
?				--wheeziness --unexplained bruising --tremor --rash

Figure A-4
Baseline Matrix Study Representation

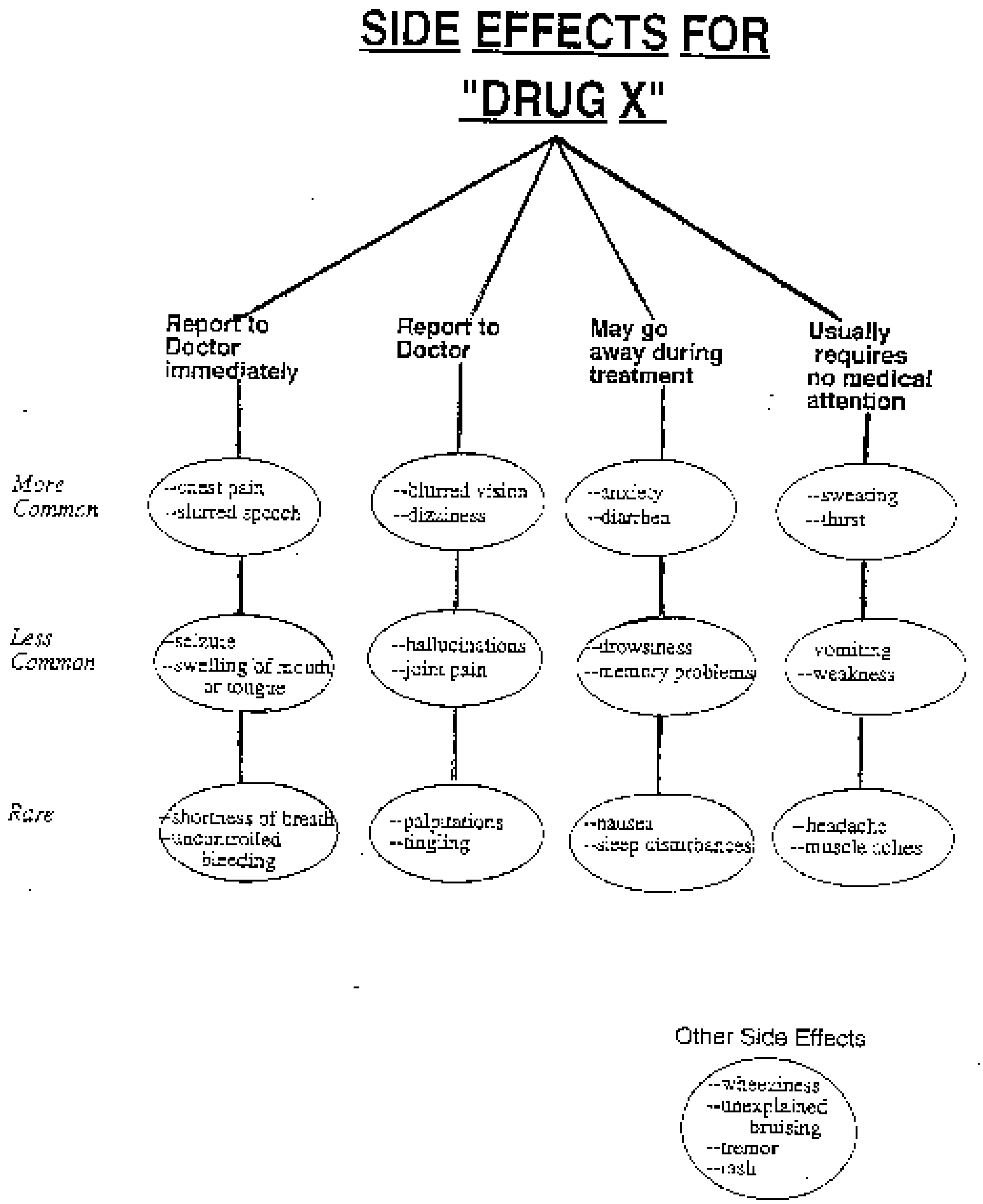


Figure A-5
Modified Tree Study Representation

SIDE EFFECTS FOR "DRUG X"

	More Common	Less Common	Rare	?
Report to Doctor Immediately	--chest pain --slurred speech	--seizure --swelling of mouth or tongue	--shortness of breath --uncontrolled bleeding	
Report to Doctor	--blurred vision --dizziness	--hallucinations --joint pain	--palpitations --tingling	
May go away during treatment	--anxiety --diarrhea	--drowsiness --memory problems	--nausea --sleep disturbances	
Usually requires no medical attention	--sweating --thirst	--vomiting --weakness	--headache --muscle aches	
?				--wheeziness --unexplained bruising --tremor --rash

Figure A-6
Modified Matrix Study Representation

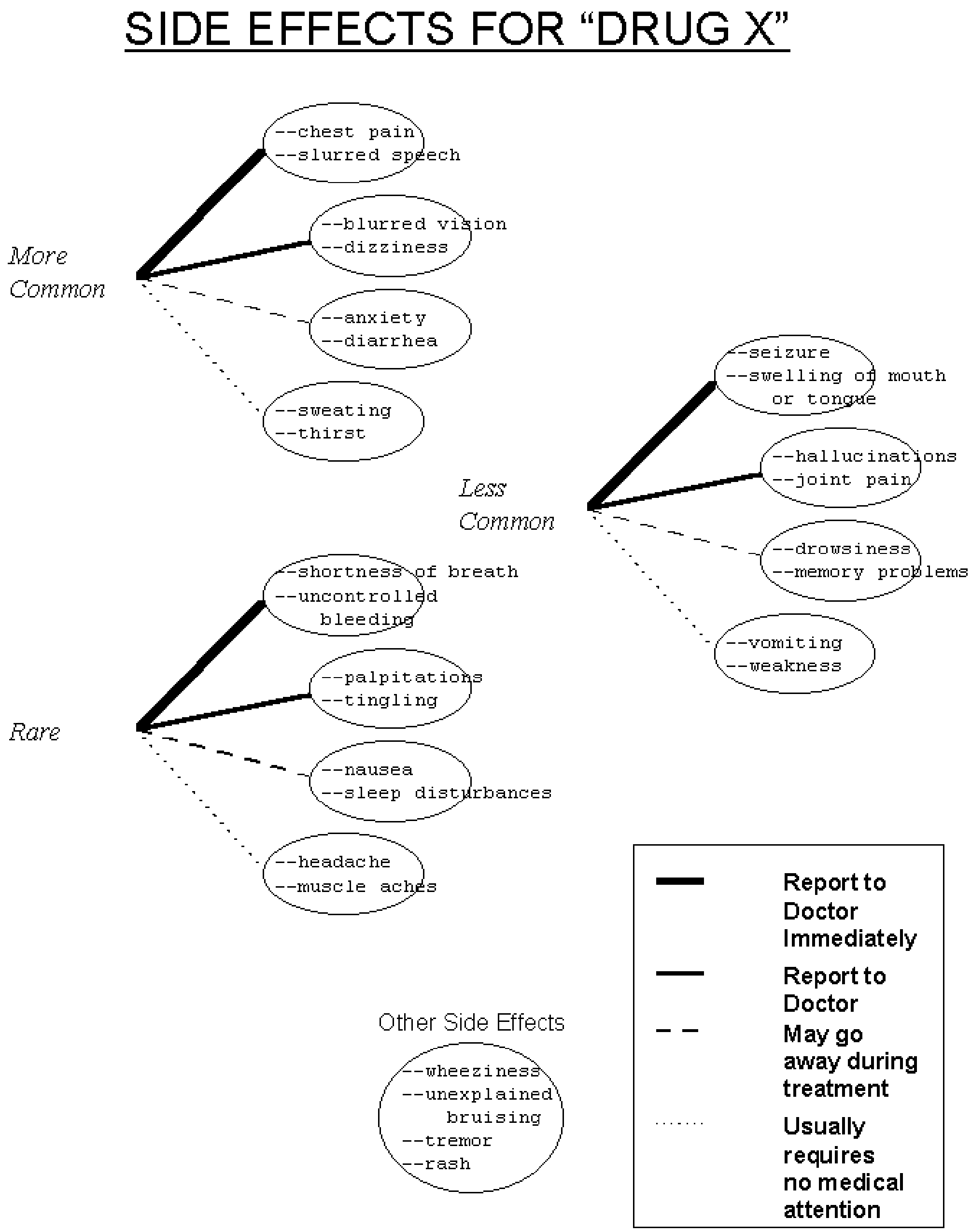


Figure A-7
Fan Study Representation

<u>SIDE EFFECTS FOR “DRUG X”</u>

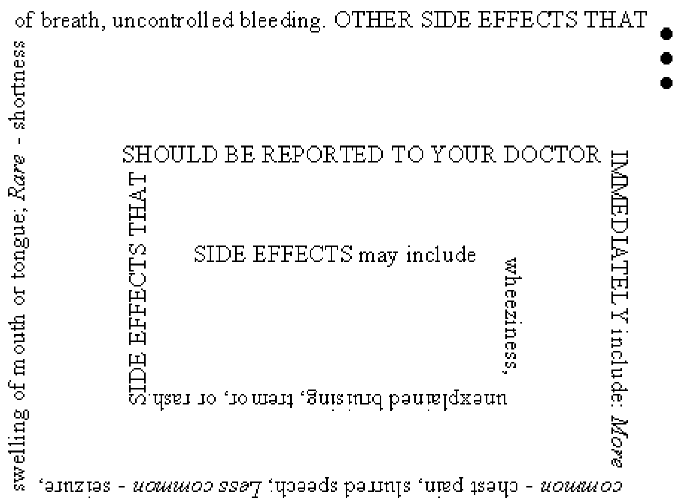


Figure A-8
Spiral Study Representation

SIDE EFFECTS FOR "DRUG X"

SIDE EFFECTS may include wheeziness, unexplained bruising, tremor, or rash. MORE COMMON SIDE EFFECTS include: *Side Effects that should be reported to your doctor immediately* chest pain, slurred speech; *Other Side Effects that should be reported to your doctor include:* blurred vision, dizziness; *Side effects that may go away during treatment include:* - anxiety, diarrhea; *Side effects that usually require no medical attention include:* - sweating, thirst. LESS COMMON SIDE EFFECTS include: *Side Effects that should be reported to your doctor immediately* - seizure, swelling of mouth or tongue; *Other Side Effects that should be reported to your doctor include:* - hallucinations, joint pain. *Side effects that may go away during treatment include:* - drowsiness, memory problems; *Side effects that usually require no medical attention include:* - vomiting, weakness; RARE SIDE EFFECTS include: *Side Effects that should be reported to your doctor immediately* - shortness of breath, uncontrolled bleeding. *Other Side Effects that should be reported to your doctor include:* - palpitations, tingling. *Side effects that may go away during treatment include:* - nausea, sleep disturbances; *Side effects that usually require no medical attention include:* - headache, muscle aches.

Figure A-9

Transposed Paragraph Study Representation

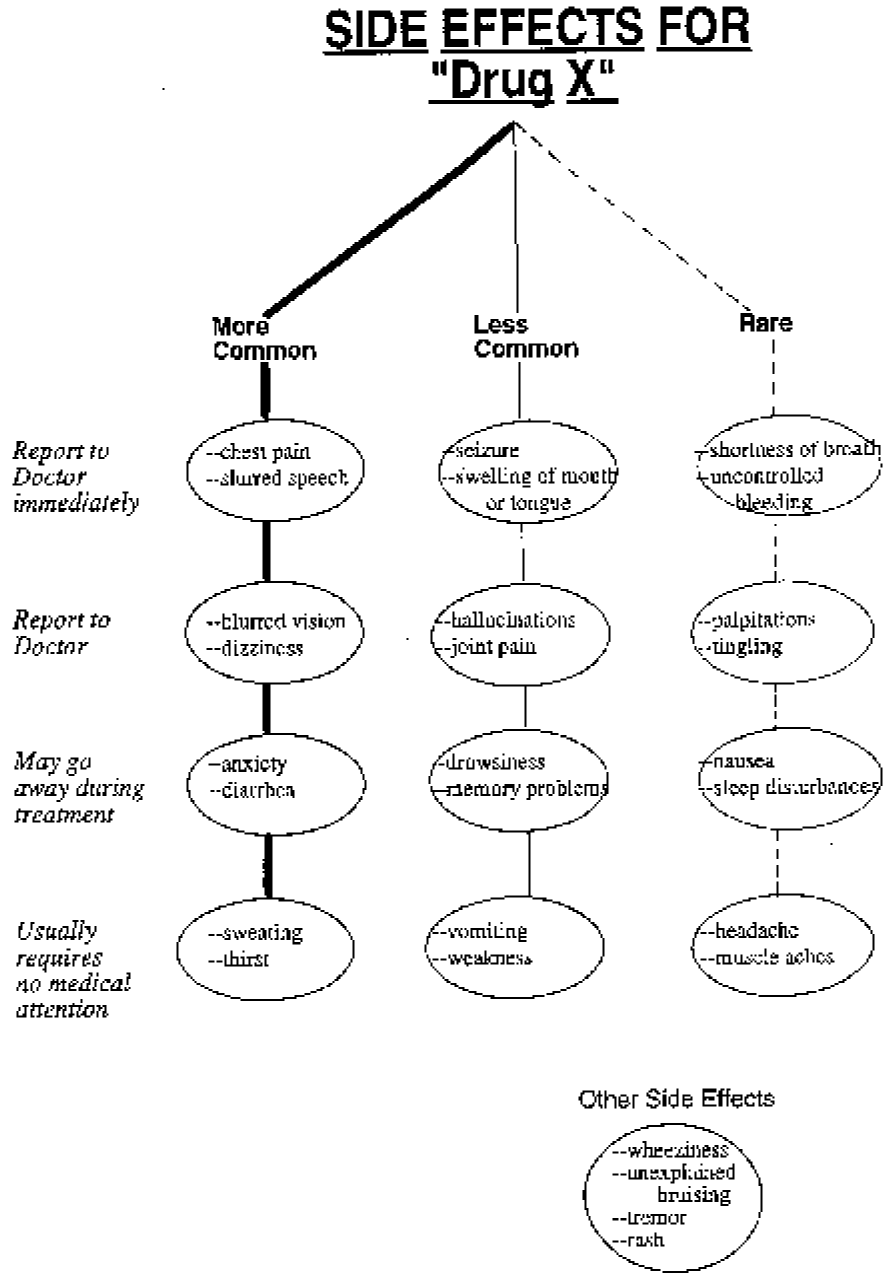


Figure A-10
Transposed Tree Study Representation

SIDE EFFECTS FOR "DRUG X"

S E V E R I T Y

F R E Q U E N C Y

	Report to Doctor Immediately	Report to Doctor	May go away during treatment	Usually requires no medical attention	?
More Common	--chest pain --slurred speech	--blurred vision --dizziness	--anxiety --diarrhea	--sweating --thirst	
Less Common	--seizure --swelling of mouth or tongue	--hallucinations --joint pain	--drowsiness --memory problems	--vomiting --weakness	
Rare	--shortness of breath --uncontrolled bleeding	--palpitations --tingling	--nausea --sleep disturbances	--headache --muscle aches	
?					--wheeziness --unexplained bruising --tremor --rash

Figure A-11

Transposed Matrix Study Representation

Appendix B. Filler Tasks

Source: UNC-Ch.
Date: 4/25/95
RSD 3/95

SE

SIDE-EFF

General Questions

1. List two common illnesses:

2. List two illnesses that require a visit to a doctor:

3. List two common illnesses suffered by college students:

4. What professional group do you predict has the most illnesses?

5. What professional group do you predict has the fewest illnesses?

6. Given a large population of college students, what percent do you think suffer illness at least:
   --once a month?______
   --once a week?______

7. Given a large population of business executives, what percent do you think suffer illness at least:
   --once a month?______
   --once a week?______

8. Given a large population of children under 10 years old, what percent do you think suffer illness at least:
   --once a month?______
   --once a week?______

9. What are five of the most common infectious diseases?

Figure B-1
Baseline Filler Task

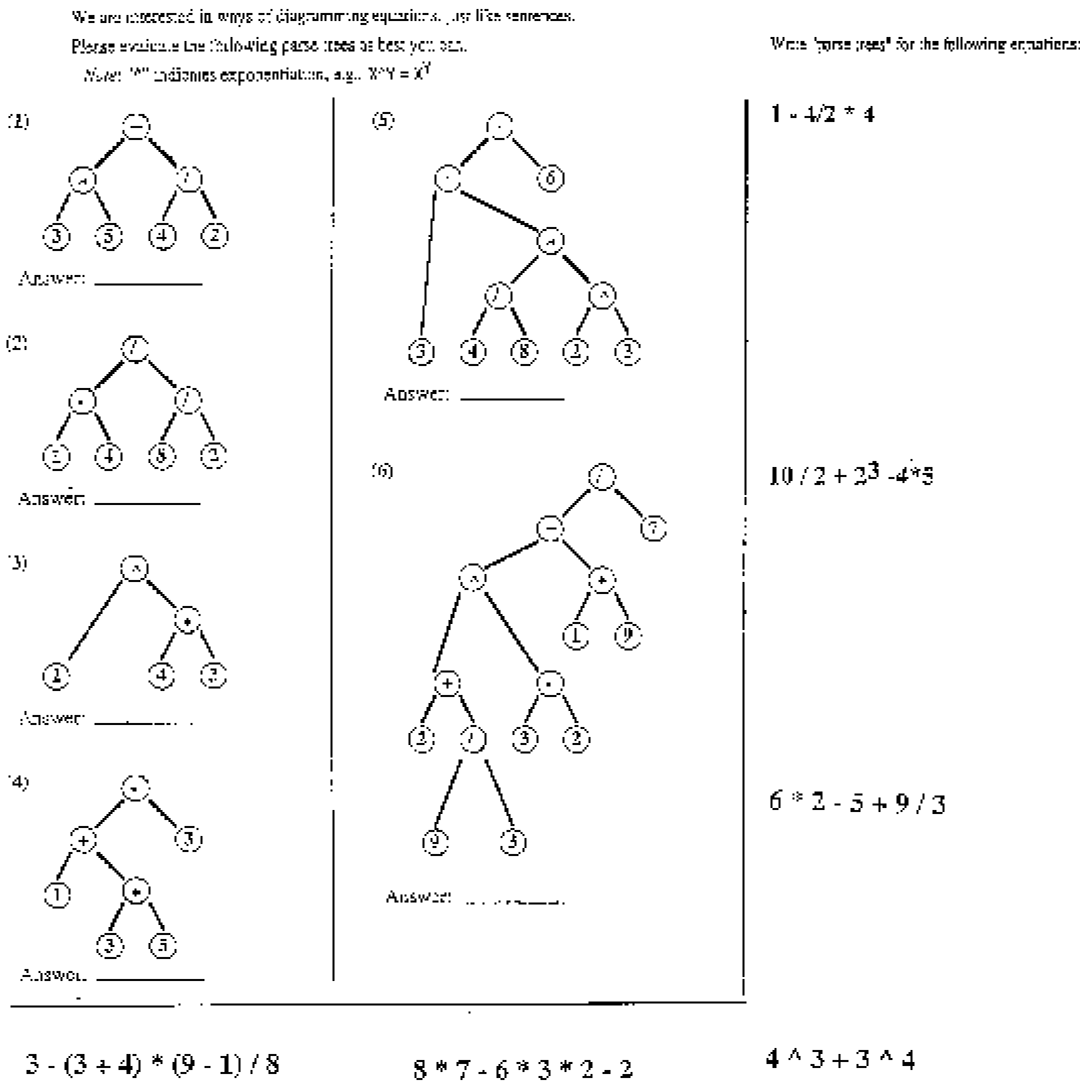


Figure B-2
Parse Tree Filler Task

We are interested in how you solve progressive matrix problems.
Please complete the following as best you can.

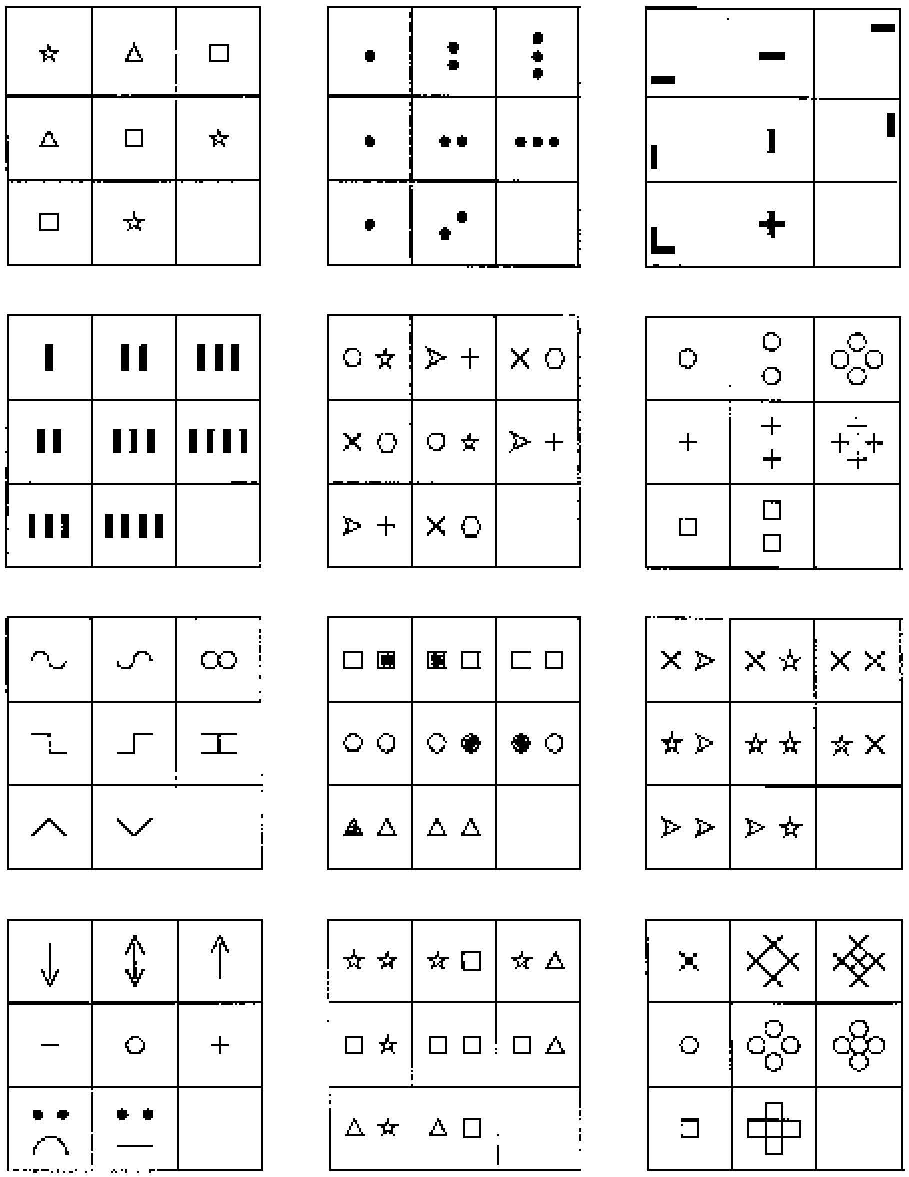


Figure B-3
Progressive Matrix Filler Task

Snack food nutrient information:

PROTEIN content: *High* - milk, beef jerky, cheddar cheese, yogurt; *Low* - chocolate bar, diet soda, jelly beans, almonds. CARBOHYDRATE content: *High* - jelly beans, yogurt, chocolate bar, milk; *Low* - beef jerky, cheddar cheese, almonds, diet soda. FAT content: *High* - almonds, cheddar cheese, milk, chocolate bar; *Low* - diet soda, beef jerky, jelly beans, yogurt.

1. How many foods are represented above?

    a) four
    b) eight
    c) twelve
    d) twenty-four

2. How many foods are high in fat?

    a) one
    b) two
    c) four
    d) eight

3. How many foods are high in carbohydrates & fat?

    a) one
    b) two
    c) four
    d) eight

4. How many foods are low in all nutrients?

    a) none
    b) one
    c) two
    d) four

5. How many foods are high in exactly two nutrients?

    a) one
    b) two
    c) three
    d) four

6. Which foods are low in carbohydrates?

    a) beef jerky & chocolate bar
    b) milk & jelly beans
    c) cheddar cheese & jelly beans
    d) beef jerky & diet soda

7. Person A's intake of food today has been low in fat. Person A is now hungry. Which of the following is the best food for Person A to eat?

    a) milk
    b) beef jerky
    c) jelly beans
    d) yogurt

8. Person B's intake of food today has been low in carbohydrates. Person B is now hungry. Which of the following is the worst food for Person B to eat?

    a) chocolate bar
    b) beef jerky
    c) yogurt
    d) jelly beans

9. Person C's intake of food today has been low in protein & fat. Person C is now hungry. Which of the following is the best food for Person C to eat?

    a) diet soda
    b) chocolate bar
    c) almonds
    d) cheddar cheese

10. Person D's intake of food today has been low in carbohydrates & fat. Person D is now hungry. Which of the following are the best foods for Person D to eat?

    a) milk
    b) chocolate bar
    c) jelly beans & almonds
    d) any of the above
    e) only (b) and (c)

Figure B-4

Food Nutrition Paragraph Filler Task

Snack food nutrient information:

PROTEIN content:
High - milk, beef jerky, cheddar cheese, yogurt.
Low - chocolate bar, diet soda, jelly beans, almonds.

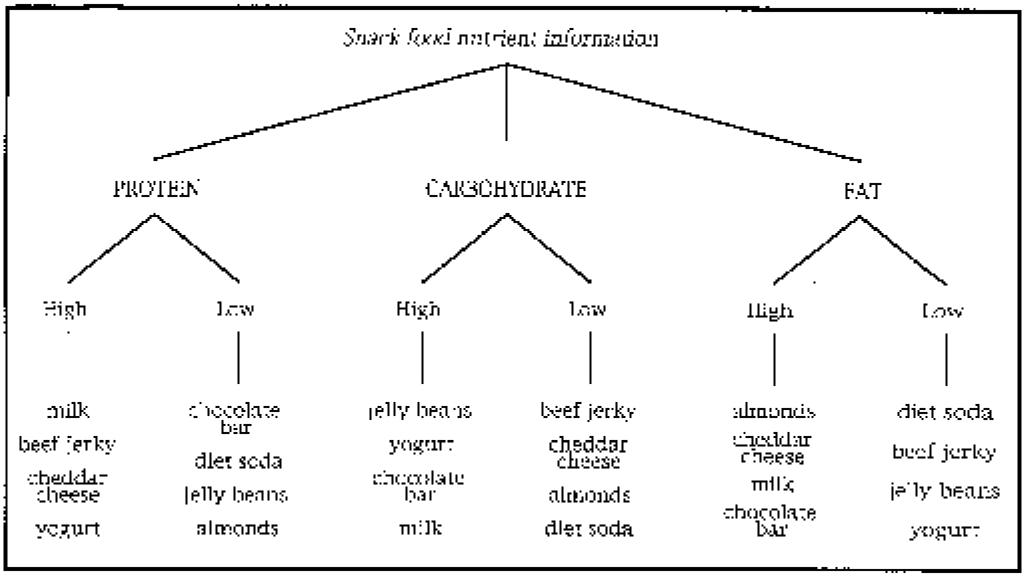
CARBOHYDRATE content:
High - jelly beans, yogurt, chocolate bar, milk.
Low - beef jerky, cheddar cheese, almonds, diet soda.

FAT content:
High - almonds, cheddar cheese, milk, chocolate bar.
Low - diet soda, beef jerky, jelly beans, yogurt.

1. How many foods are represented above?
   a) four
   b) eight
   c) twelve
   d) twenty-four
2. How many foods are high in fat?
   a) one
   b) two
   c) four
   d) eight
3. How many foods are high in carbohydrates & fat?
   a) one
   b) two
   c) four
   d) eight
4. How many foods are low in all nutrients?
   a) none
   b) one
   c) two
   d) four
5. How many foods are high in exactly two nutrients?
   a) one
   b) two
   c) three
   d) four
6. Which foods are low in carbohydrates?
   a) beef jerky & chocolate bar
   b) milk & jelly beans
   c) cheddar cheese & jelly beans
   d) beef jerky & diet soda
7. Person A's intake of food today has been low in fat. Person A is now hungry. Which of the following is the best food for Person A to eat?
   a) milk
   b) beef jerky
   c) jelly beans
   d) yogurt
8. Person B's intake of food today has been low in carbohydrates. Person B is now hungry. Which of the following is the worst food for Person B to eat?
   a) chocolate bar
   b) beef jerky
   c) yogurt
   d) jelly beans
9. Person C's intake of food today has been low in protein & fat. Person C is now hungry. Which of the following is the best food for Person C to eat?
   a) diet soda
   b) chocolate bar
   c) almonds
   d) cheddar cheese
10. Person D's intake of food today has been low in carbohydrates & fat. Person D is now hungry. Which of the following are the best foods for Person D to eat?
   a) milk
   b) chocolate bar
   c) jelly beans & almonds
   d) any of the above
   e) only (b) and (c)

Figure B-5

Food Nutrition Outline Filler Task



1. How many foods are represented above?
   a) four
   b) eight
   c) twelve
   d) twenty-four
2. How many foods are high in fat?
   a) one
   b) two
   c) four
   d) eight
3. How many foods are high in carbohydrates & fat?
   a) one
   b) two
   c) four
   d) eight
4. How many foods are low in all nutrients?
   a) none
   b) one
   c) two
   d) four
5. How many foods are high in exactly two nutrients?
   a) one
   b) two
   c) three
   d) four
6. Which foods are low in carbohydrates?
   a) beef jerky & chocolate bar
   b) milk & jelly beans
   c) cheddar cheese & jelly beans
   d) beef jerky & diet soda
7. Person A's intake of food today has been low in fat. Person A is now hungry. Which of the following is the best food for Person A to eat?
   a) milk
   b) beef jerky
   c) jelly beans
   d) yogurt
8. Person B's intake of food today has been low in carbohydrates. Person B is now hungry. Which of the following is the worst food for Person B to eat?
   a) chocolate bar
   b) beef jerky
   c) yogurt
   d) jelly beans
9. Person C's intake of food today has been low in protein & fat. Person C is now hungry. Which of the following is the best food for Person C to eat?
   a) diet soda
   b) chocolate bar
   c) almonds
   d) cheddar cheese
10. Person D's intake of food today has been low in carbohydrates & fat. Person D is now hungry. Which of the following are the best foods for Person D to eat?
    a) milk
    b) chocolate bar
    c) jelly beans & almonds
    d) any of the above
    e) only (b) and (c)

Figure B-6

Food Nutrition Tree Filler Task

Nutrient Information

Snack food	PROTEIN	CARBOHYDRATE	FAT
milk	✓	✓	✓
yogurt	✓	✓	
beef jerky	✓		
cheddar cheese	✓		✓
chocolate bar		✓	✓
almonds			✓
jelly beans		✓	
diet soda			

✓ High
☐ Low

1. How many foods are represented above?
   a) four
   b) eight
   c) twelve
   d) twenty-four
2. How many foods are high in fat?
   a) one
   b) two
   c) four
   d) eight
3. How many foods are high in carbohydrates & fat?
   a) one
   b) two
   c) four
   d) eight
4. How many foods are low in all nutrients?
   a) none
   b) one
   c) two
   d) four
5. How many foods are high in exactly two nutrients?
   a) one
   b) two
   c) three
   d) four
6. Which foods are low in carbohydrates?
   a) beef jerky & chocolate bar
   b) milk & jelly beans
   c) cheddar cheese & jelly beans
   d) beef jerky & diet soda
7. Person A's intake of food today has been low in fat. Person A is now hungry. Which of the following is the best food for Person A to eat?
   a) milk
   b) beef jerky
   c) jelly beans
   d) yogurt
8. Person B's intake of food today has been low in carbohydrates. Person B is now hungry. Which of the following is the worst food for Person B to eat?
   a) chocolate bar
   b) beef jerky
   c) yogurt
   d) jelly beans
9. Person C's intake of food today has been low in protein & fat. Person C is now hungry. Which of the following is the best food for Person C to eat?
   a) diet soda
   b) chocolate bar
   c) almonds
   d) cheddar cheese
10. Person D's intake of food today has been low in carbohydrates & fat. Person D is now hungry. Which of the following are the best foods for Person D to eat?
   a) milk
   b) chocolate bar
   c) jelly beans & almonds
   d) any of the above
   e) only (b) and (c)

Figure B-7

Food Nutrition Matrix Filler Task

Appendix C. Response Sheets

Source: ________
Date: ________
RH - 11/95

Name: ____________________

SIDE-MEM
Ratings

Severity Scale

- 4 = Report to Doctor Immediately
- 3 = Report to Doctor
- 2 = May Go Away during Treatment
- 1 = Usually Requires no Medical Attention
- 0 = not given

Frequency Scale

- 3 = More Common
- 2 = Less Common
- 1 = Rare
- 0 = not given

	Severity	Frequency		Severity	Frequency
1)	____	____	15)	____	____
2)	____	____	16)	____	____
3)	____	____	17)	____	____
4)	____	____	18)	____	____
5)	____	____	19)	____	____
6)	____	____	20)	____	____
7)	____	____	21)	____	____
8)	____	____	22)	____	____
9)	____	____	23)	____	____
10)	____	____	24)	____	____
11)	____	____	25)	____	____
12)	____	____	26)	____	____
13)	____	____	27)	____	____
14)	____	____	28)	____	____

Figure C-1
Baseline Response Sheet

Source: ____________
Date: ____________
RH/WBB 3/96

Name: ____________________
FS

SIDE-MEM
Ratings

Frequency Scale

- 3 = More Common
- 2 = Less Common
- 1 = Rare
- 0 = not given

Severity Scale

- 4 = Report to Doctor Immediately
- 3 = Report to Doctor
- 2 = May Go Away during Treatment
- 1 Usually Requires No Medical Attention
- 0 = not given

	Frequency	Severity		Frequency	Severity
1)	________	________	15)	________	________
2)	________	________	16)	________	________
3)	________	________	17)	________	________
4)	________	________	18)	________	________
5)	________	________	19)	________	________
6)	________	________	20)	________	________
7)	________	________	21)	________	________
8)	________	________	22)	________	________
9)	________	________	23)	________	________
10)	________	________	24)	________	________
11)	________	________	25)	________	________
12)	________	________	26)	________	________
13)	________	________	27)	________	________
14)	________	________	28)	________	________

Figure C-2
Modified Response Sheet

Source: UMC-Ph
Date: 4/25/95
RSD/MRC-3/95

Name:________________

SF

SIDE-MEM
Ratings

Severity Scale

4 = Report to Doctor Immediately
3 = Report to Doctor
2 = May Go Away during Treatment
1 = Usually Requires no Medical Attention
0 = not given

1)______	15)______
2)______	16)______
3)______	17)______
4)______	18)______
5)______	19)______
6)______	20)______
7)______	21)______
8)______	22)______
9)______	23)______
10)______	24)______
11)______	25)______
12)______	26)______
13)______	27)______
14)______	28)______

Figure C-3
Severity-only Response Sheet

Source: UMC-Ph
Date: 1/25/95
RSD/MRC-5/95

Name:____________________

SIDE-MEM
Ratings

Frequency Scale

3 = More Common
2 = Less Common
1 = Rare
0 = not given

1)______	15)______
2)______	16)______
3)______	17)______
4)______	18)______
5)______	19)______
6)______	20)______
7)______	21)______
8)______	22)______
9)______	23)______
10)______	24)______
11)______	25)______
12)______	26)______
13)______	27)______
14)______	28)______

Figure C-4
Frequency-only Response Sheet

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Biography

Robert Charles Hubal was born in San Pedro, CA in 1965 to Susan and Gerald Hubal, but grew up in normal fashion in Vestal, NY. He graduated from Vestal Senior High School in 1983 with little effort; from the Massachusetts Institute of Technology with an S.B. in Computer Science and Engineering in 1987 with considerable effort; from North Carolina State University with an M.S. in Computer Science in 1992 with a perfect grade point average; and from Duke University with a Ph.D. in Cognitive Psychology in 1996 with this document. In a life prior to graduate school he worked at International Business Machines and at Andersen Consulting, his work taking him from upstate New York to the City, to Boston, Chicago, and even Zürich. He lives in Raleigh with Elaine Cohen Hubal (a recent Ph.D. as well!), his wife of nearly eight years.