SOLVING FOUR WORD ANALOGY PROBLEMS: THE ROLE OF SPECIFICITY AND INCLUSIVENESS

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ABSTRACT

The present work examined subjects' performance on eight types of four word analogy problems. Two critical dimensions distinguish among these analogy types: specificity and inclusiveness. Whole-part analogies such as **hand : palm** as **foot : sole** (read *hand is to palm as foot is to sole*) are specific because the association appearing in the two word pairs consist of spatial/functional relationships which are highly similar to each other. In contrast, analogies such as **car : wheel** as **boat : mast** are nonspecific because they use whole-part associations which are less similar to each other. Analogies are inclusive if they use relatively direct associations, as in the whole-part association illustrated by **car : wheel**. In contrast, noninclusive analogies require additional inferences between words, as illustrated in the part-part association **bumper : wheel,** which requires the object **car** to be inferred. Responses from undergraduate university subjects show that both inclusive and specific analogy problems were solved more quickly than their noninclusive and nonspecific counterparts, respectively. Experiment 1 illustrated these specificity and inclusiveness effects both in a recognition (multiple choice) paradigm, and a recall paradigm where subjects spoke their own answer choices aloud.

Subsequent experiments were performed to examine the role of the association types and the role of word attributes in subjects' processing of these analogy problems. Experiment 2 attempted to prime subjects with the association type used in each block of analogy problems, but showed a very modest effect on solution latencies. In Experiment 3 reordering the words within analogy problems unexpectedly increased the latencies for many problems, apparently because different words appeared in the third word positions within them.

Experiments 4 and 5 focussed directly on the study of specificity. Experiment 4 showed that the processing benefit found for specific analogies is due to the close match of word attributes between word pairs, not due to the attributes of the particular words used. Experiment 5 manipulated the taxonomic similarity of the subject matter addressed by the two pairs of words, and found that the use of word pairs from more taxonomically distant subject areas increased solution latencies for some analogy types.

Experiment 6 required subjects to group analogy problems into categories they defined. This procedure validated six of the eight analogy types used in this thesis; the specificity distinction was not evident among the groups of problems formed by subjects.

The discussion of these results supports a theoretical model of problem solving four word analogies which incorporates a stage-like, componential processing for nonspecific types, and a faster, more automatic processing for specific types. The discussions of empirical and theoretical work in this thesis also focussed more widely on its relevance to more practical uses of analogies in problem solving.

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CHAPTER ONE-- INTRODUCTION AND OVERVIEW

Analogies are effective in teaching because they give information beyond the most apparent features shared between two objects. To illustrate the richness of information conveyed by an analogy consider, for example, the claim that a particular woman is the Wayne Gretsky of motherhood. The information conveyed by this analogy extends as far as the knowledge we have about mothers and about Wayne Gretsky. It suggests that the woman is a highly skilled mother. To the knowledgeable hockey fan this analogy also indicates that she is outwardly selfless, ready to acknowledge the help of others, and generally acts with humility. Because analogies are capable of conveying complex and large amounts of information in an efficient manner, they are used extensively in teaching and everyday situations. But despite their important role in communication the question of how we use and comprehend analogies has received relatively little experimental study.

The extant literature addresses several aspects of how analogies are processed. Most recent work has focussed on metaphors and problem solving by analogy (see Vosniadou & Ortony, 1989). In contrast, the study of four word analogies, such as **fish : school** as **goose : gaggle** (read "fish is to school as goose is to gaggle"), has received less attention. But, the few studies that have been reported focussed on a wide range of issues. Whitely (1976, 1977a; Whitely & Dawis, 1974; Whitely & Barnes, 1979) has studied such word analogies in order to determine their psychometric use in the measurement of intelligence. For example, Barnes and Whitely (1981) examined the effect of word order (eg. **fish : school** as **goose : gaggle** vs **fish : goose** as **school : gaggle**) on how difficult it is to solve four word analogies. Willner (1964) and Powell and Vega (1971) have investigated the role of word associations on subjects' tendency to respond to four word analogies with an appropriate solution. Sternberg (1977) has examined the mental processes used by subjects in solving four word analogies; his goal was to determine the relative amount of processing time spent encoding, inferring, mapping and applying the information contained in word analogies. In combination, this diverse collection of studies has helped to form a preliminary understanding of the cognitive processes involved in solving analogies.

Previous work has demonstrated that the associations among the words that make up an analogy determine the difficulty of that analogy. Previous research examined how solving analogies is affected by associations of different strengths, by the order of presenting the words that make up the analogy problem, and by subjects' familiarity with different types of analogies. However, to my knowledge, previous investigators have not examined the effects due to different kinds of inter-word associations such as part-whole (eg. **hand : palm** as **foot : sole**) and same class (eg. **orange : apple** as **carrot : corn**). What is the effect of different associations on our ability to comprehend analogies?

Four word analogies such as **fish : school** as **goose : gaggle** include two pairs of words with a common type of association between each pair. When solving such an analogy we must infer the association between the first pair of words (**fish : school**) and use it to match the third word (**goose**) with a solution word. The analogy above requires the subject to recognize the member-group association between **fish** and **school**, and to apply it to the word **goose** to discover the solution word **gaggle**. In this way, four word analogies tap subjects' ability to make inferences about the association between words and to search and retrieve words based on these inferred associations.

The overall goal of my thesis was to examine how different types of associations between words influence subjects' ability to solve four word analogies. Does the particular association between paired words (eg. **goose : gaggle**) have a significant influence on solving analogies, or are the processes involved in solving analogies primarily determined by aspects of the individual words themselves? Does the member-group association between a pair of words like **goose** and **gaggle** have the same effect or a different effect on processing than, for example, the same class association between **orange** and **apple**? These and related questions motivated the series of experiments that is reported in this thesis.

The general motivation for pursuing these goals comes from two areas of cognition. The first is work on theories of semantic memory, especially their specific assumptions about how relations between words are represented and processed. Models of long-term memory such as Collins and Quillian's (1969) assume a hierarchical system of storage. The model of Smith, Shoben and Rips (1974) proposes that concepts are stored as feature lists and that some features are more important than others in making decisions about similarity between items. A better understanding of how we process relationships between words could provide new insights into semantic memory and advance our ability to explain subjects' performance on a variety of tasks (in addition to solving analogies), such as sentence verification. A systematic study of how different types of associations are processed would also provide useful background information for other investigations, including those concerned with the classification of word association responses, or the effectiveness of mnemonic strategies.

A second motivation for my work comes from the domain of problem solving. The cognitive activities involved in problem solving include the encoding of a problem (the given information about a problem) and the recognition and use of associations relevant to its solution. The importance of these activities is illustrated by Dunker's (1945) Two String problem. In this problem, the subject is asked to tie together two strings hanging from a ceiling. The length of one string is not sufficient to extend to another that is hanging stationary. To join the strings, the subject must discover and use a pendulum motion by catching the swinging strings at a point midway between them. That is, the subject must associate the strings with their potential action as a pendulum. Judson, Cofer and Gelfand (1956) discovered that subjects could be primed to use the string as a pendulum through the incidental inclusion of the words *rope, swing, pendulum, clock,* and *time* in a prior word association task. Subject who were primed in this manner solved the problem more readily. This finding suggests that success in practical problem solving is influenced by subjects' ability to recognize associations that exist among objects in the problem. My thesis will illuminate the processes involved in discovering associations between words, and the processes used to initiate and guide memory retrieval for solutions to four-word analogy problems.

Specific Goals

What are the processes involved in solving four word analogies? What processes focus directly on the association between the paired words in an analogy? What is the influence of the individual words, versus the associations between words, on subjects' ability to solve four word analogies? My thesis includes six experiments that examine these and related questions.

My work is based on the general assumption that the basic processes involved in solving analogies are revealed by subjects' performance on different types of four word analogy problems. My experimental work tapped into these processes by measuring subjects' solution speed and accuracy on analogies defined by different association types. For example, the analogy **car : wheel** as **boat : mast** contains a whole-part association between the two pairs of words, whereas the analogy **fruit : apple** as **vegetable : corn** uses a super/subordinate association. If these two types of analogy problems produce a consistent difference in solution times, I view this difference as reflecting different underlying cognitive processes.

Many other types of associations exist in addition to whole-part and super/subordinate types. I assume that associations vary along a few psychologically meaningful dimensions which reflect the operation of basic cognitive procedures. The thesis focusses on two such dimensions: specificity and inclusiveness. A model depicting these dimensions and an example of each analogy type illustrating these dimensions appears as Figure 1.

The specificity dimension is highlighted by the difference between the following two analogies: **hand : palm** as **foot : sole** and **car : wheels** as **boat : mast**. Although both involve a whole-part association between the paired words, the crucial difference between them is that in the former, the specific spatial and/or functional relationship between **hand : palm** is repeated in **foot : sole**. In contrast, the same degree of specificity does not hold between words in the latter analogy; any part of boat would be appropriate for the second analogy. The same specificity difference is illustrated in the following two analogies using a part-part association: **hand : elbow** as **foot : knee**, and **bumper : wheels** as **hull : mast**. In both cases the word pairs are parts of a common object. However, whereas **knee** is the specific body part that replicates the spatial/functional relationship illustrated by **hand: elbow** in the first analogy, in the second analogy the word **mast** does not have a similarly specific relationship to **hull** as the one existing in the pair **bumper : wheels**. Thus, specificity refers to the degree to which the fourth word in the analogy is specifically defined by the relationship existing within each pair of words in the analogy. As will be discussed later, a general hypotheses of my thesis is that more specific associations between paired words facilitate subjects' ability to solve analogy problems.

The second critical dimension that characterizes the difference between analogies is inclusiveness. It is illustrated by the following examples: **bumper : wheels** as **hull : mast**, and **car : wheels** as **boat : mast**. Both of these analogies are similar on the specificity dimension (they are both nonspecific), but they differ on inclusiveness. Inclusive analogies are made up of items where one term includes the other. For example, a whole-part association is inclusive

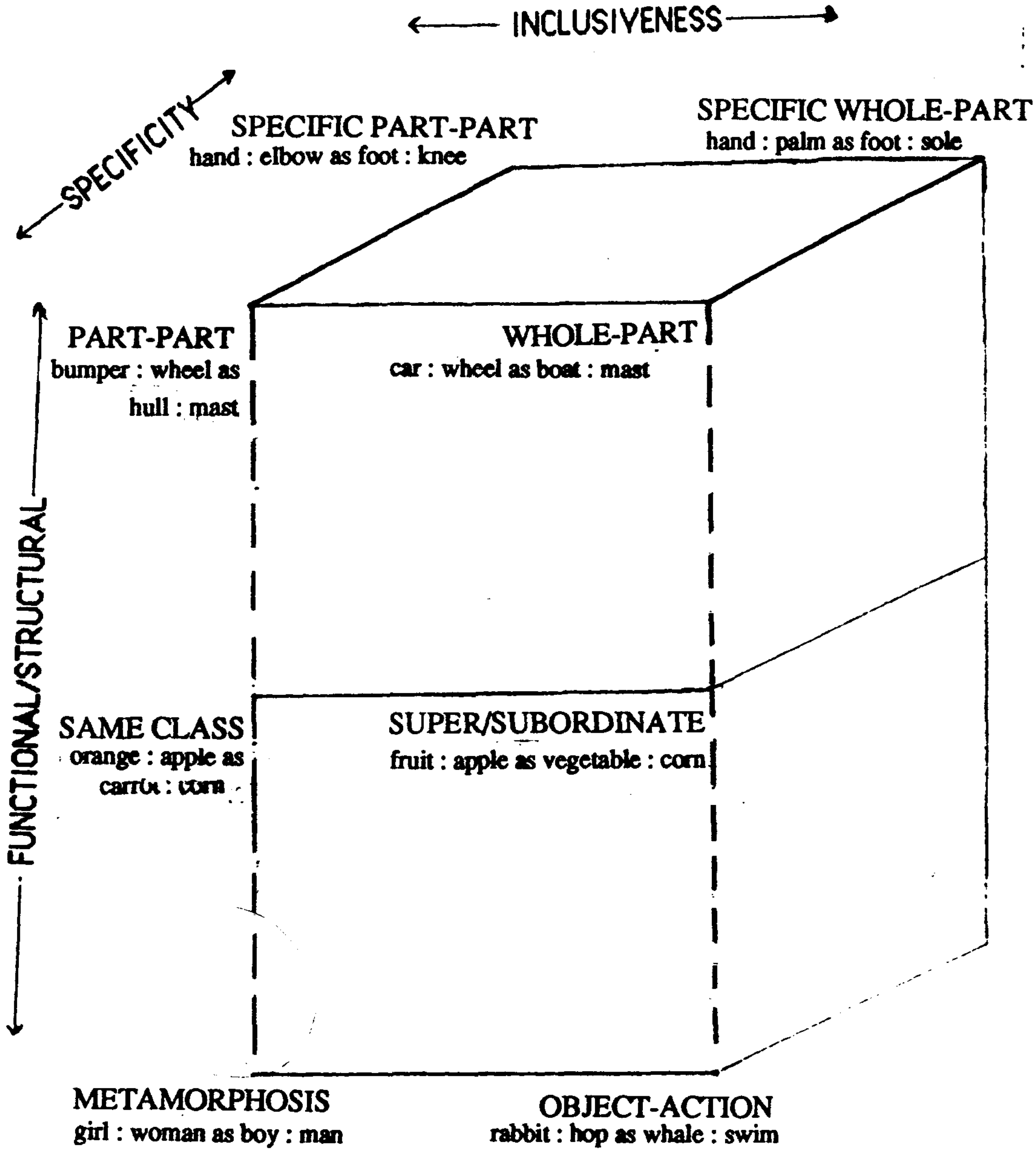


Figure 1. Three dimensional model of a proposed typology of analogy types.

because the part is contained within the whole, whereas a part-part association is noninclusive because it requires the subject to infer the whole that relates the two parts. Other pairs of associations are also distinguished by inclusiveness. For example, one critical difference between super/subordinate analogies such as **fruit : apple** as **vegetable : corn** and same class analogies such as **orange : apple** as **carrot : corn**, is inclusiveness. In the former, the inclusive association relates an instance and the category to which it belongs; in the latter noninclusive analogy the association relates two instances, and requires the category to be inferred. Likewise, object-action analogies such as **rabbit : hop** as **whale : swim** and metamorphosis analogies such as **girl : woman** as **boy : man**, use inclusive and noninclusive associations, respectively. The former analogy pairs an object directly with its typical action, whereas the latter requires an action or process to be inferred for the relationship between the words to be understood. As will be discussed later, my thesis examined the general hypothesis that analogies defined by inclusive associations are solved more easily than those defined by noninclusive ones.

Figure 1 shows how specificity and inclusiveness are related. Combining these two dimensions yields the square on the top tier of the figure. Each corner of the square defines a particular type of analogy problem. These are part-part, whole-part, and the two specific versions of these types: specific part-part and specific whole-part. Throughout this thesis, my primary focus will be directed toward these four types of analogies, and how solving them is affected by specificity and inclusiveness.

The thesis also explored other dimensions among the associations that might influence subjects' ability to solve four word analogy problems. One of these I have tentatively called a functional/structural dimension. Figure 1 shows this as the third dimension of a cube. Please note the dotted line in the figure; it emphasizes the currently ill-defined nature of this dimension. The functional/structural dimension does not have the same status as specificity and inclusiveness in this thesis. It was added primarily to explore a broader range of analogy types, and to examine whether the pairs of analogies appearing at each of the three levels of this dimension are also influenced by inclusiveness. The primary goal of my thesis was to examine the influence of two critical dimensions -- specificity and inclusiveness -- on subjects' ability to solve different types of analogy problems.

Basic Assumptions

The general hypotheses guiding the present investigation were based on the following critical processing assumptions. First, it was assumed that solving a four word analogy problem includes a series of processing components including i) identifying the first two terms of the analogy (eg. **hand : palm**), ii) inferring the association between these two words, iii) mapping this association onto the third term (eg. **foot**) to find a set of possible solutions, and iv) selecting a response from that set. The second assumption was that the completion of each of these components adds to the total time required to solve an analogy problem. The third assumption was that the amount of time required by at least one of these processing components varies across analogy types. For example, a highly specific analogy is made up of two pairs of words which both have very similar relationships between them. This should enhance the ease with which the association recognized in the first word pair can be applied to the second word pair, because specificity serves to target a relatively small set of potential solutions from which to select a response. This reasoning underlies what I call the specificity hypothesis: it claims that the search for a solution word in specific analogies is faster than for nonspecific analogies.

The thesis also focusses on what I call the inclusiveness hypothesis, the claim that noninclusive analogies require an extra amount of processing to recognize the nature of the association between the first word pair. Extra processing time is needed because noninclusive associations, by definition, require the subject to perform an additional inference to identify the association between each pair of words.

Thesis Overview

The thesis includes nine additional chapters. Chapter two reviews previous research on the role of associations in analogies. This chapter first addresses the view of Dreistadt (1968) and Oppenheimer (1956) that the ability to understand and produce analogies is primarily a matter of recognizing similar associations in two different content areas. The remainder of chapter two reviews previous research on word associations and how they are treated by extant models of semantic memory. This work is relevant because it motivated the selection of analogy problem types for my work, and it focussed my efforts on specificity and inclusiveness.

Chapter three develops the theoretical model that underlies the hypotheses that were tested in my work, and that provides the framework for my findings. The chapter begins by reviewing the theoretical and empirical work conducted on the use of analogical thinking in solving Dunker's (1945) problems, and the findings from the study of analogy problem solving in the field of artificial intelligence. The chapter then describes Sternberg's processing model for processing four word analogy problems. My modification of this model is then presented as an integration of the processing principles observed in the problem solving literature with the four word analogy paradigms I use. The result is a componential model of cognitive processing which accommodates a procedural account of the solution latencies observed for highly specific analogy problems.

Chapter four describes the basic method that was used for all my work. It also reports the findings of pilot studies which influenced the final selection of materials for the present work.

Chapter five reports the results of Experiment 1, which demonstrate the usefulness of my method as an effective tool for studying the processing of four word analogy problems. This chapter also presents evidence that inclusiveness and specificity enable subjects to solve analogy problems faster.

Chapter six reports an experiment that investigated whether solving analogies could be enhanced by priming. This was done by presenting ten different items of each analogy type in a series. It was assumed that a blocked, as opposed to random, presentation of ten problems of the same type would prime the association type on which they were based. If the nature of the association is a crucial determinant of processing, then this type of manipulation should facilitate solving analogies. Alternatively, if the blocked presentation of items does not facilitate processing, it may be inferred that the different words used in different analogies prevent subjects from realizing the nature of the association common to all problems within a block.

In Chapter seven, Experiment 3 is reported. In this experiment the analogy problems used in the earlier experiments were manipulated such that the order of the words presented within each pair was reversed. By this method, whole-part analogy problems became part-whole problems and object-action problems become action-object problems, etc. This manipulation was used to investigate how subjects' ability to solve analogy problems was influenced by the type of associations between paired words, as opposed to the meanings of the words themselves. The reordering manipulation was expected to affect processing of some analogy types such as whole-part which becomes part-whole, but not others such as part-part which do not change the nature of their association.

Chapter eight reports two experiments (4 and 5) that focused directly on the specificity dimension. Experiment 4 tested the influence exerted by the particular words that occupied the third word position in each analogy problem. The question tested was whether the specificity of a problem could be manipulated independent of the words used. Experiment 5 investigated the role of specificity in problem solving by manipulating the similarity of the content areas addressed by the two pairs of words in each problem. The hypothesis motivating this experiment states that greater content similarity (specificity) between the two word pairs within an analogy problem should facilitate its solution.

Chapter nine reports the final experiment (Experiment 6) that presented subjects with a sorting task. This task required them to group eighty analogy items into coherent categories defined by the subject. This procedure was used to validate the assignment of each problem to the eight analogy types used in this thesis.

The final chapter, the General Discussion, summarizes the main findings, outlines their limitations, and highlights what these findings reveal about the processes involved in solving analogy problems. In doing this, the chapter also underscores the methodological and theoretical contributions of my thesis, and outlines directions for future work.

CHAPTER TWO: LITERATURE REVIEW OF THE ROLE OF ASSOCIATIONS IN ANALOGIES, WORD ASSOCIATIONS, AND SEMANTIC MEMORY

Overview

This chapter and the next provide the theoretical background for my experimental work. This chapter's major goal is to justify the choice of analogy types. The goal of the next chapter is to provide the theoretical background for the processing model I propose to explain how four word analogy problems are solved.

This chapter has three sections. The first argues that associations between the semantic representations of concepts (such as words, objects, or ideas) are crucial elements in analogical reasoning. The critical role of associations is highlighted by the everyday use of analogies in situations where two dissimilar topics are compared to show their similarity through an analogy. The second section reviews previous attempts to derive a typology of associations such as studies classifying the results of a free association task. In the third section additional suggestions as to the nature of such a typology will be derived by observing the types of associations used in semantic memory theories.

Section 2.1: The Role of Associations in Analogical Thinking

Illustrations of Everyday Uses

The use of analogies in science, philosophy and in everyday thinking is widespread. Some illustrations serve to highlight the thought processes that underlie the use of analogies, and emphasize the critical role that associations play in connecting representations stored in memory when analogical comparisons are produced. Three general uses of analogical comparisons are illustrated: their use in forming explanations, in forming metaphor, and in solving problems. These illustrations all demonstrate that the task of creating and understanding analogy is essentially the process of forming pairs of similar associations in two distinct subject areas. These illustrations also show that this process can occur with the deliberate use of analogical comparisons and with more implicit uses.

Analogical Associations Used Explicitly In Explanations

Consider a high school biology teacher explaining the basic structure and functions of a cell. In searching for an explanatory vehicle, the task becomes one of finding a content area which includes a set of concepts similar to those that need to be explained regarding the biology of the cell. For cell biology these concepts are i) a semi-permeable membrane where some materials are permitted entry while others are not, ii) a central location where planning and instructions are initiated and coordinated, iii) a storehouse of energy required for creating refined products from the materials imported to the structure, iv) a work area for carrying out this activity, and v) a mechanism for transporting and storing both the end product and the resulting waste materials.

What vehicle of explanation is most appropriate in this context? Educators have used the factory analogy. What makes this analogy useful is that the factory and the cell are defined by many similar associations among the concepts contained within them. The mitochondria is a reservoir of energy, like a fuel tank in a factory. This energy in turn is critical for achieving the goals of the enterprise. The cell wall is analogous to the factory receiving area in that they both control the import/export of construction materials, and both exert a degree of quality control that ensures the supply of raw materials is not affected by shortages or impurities. The cell's nucleus is like the business office: a place for making decisions and for controlling other components of the system. In this way the analogy works by exploiting the structure of a known system in order to elucidate the structure of a new, unknown system.

This example provides an important illustration that analogies can, and do, work even when there is no taxonomic or material similarity between the target domain and the compared object, or *vehicle*, in the analogy. The cell/factory analogy works even though (and perhaps because) cells and factories are very different things that do not share any superficial or material similarities. Analogies work by focusing the learner's attention on the meaningful associations among concepts within a known domain, such as a factory. My work is founded on the assumption that the ease with which we comprehend an analogy is determined by the salience of these associations and our ability to realize when the same associations exist in a target and a vehicle domain.

Analogical Associations Used Implicitly In Metaphors

The cell/factory example illustrates how the structure of associations in two domains is used to make comparisons even when these domains share few or no superficial features. The same use of associations occurs in a more striking manner by metaphorical expressions such as **argument is war**. This example also illustrates that the associations contained within a known vehicle may be transferred to the second, target domain, without the associations themselves being explicitly referred to, nor perhaps even consciously recognized.

In their book Metaphors we live by, Lakoff and Johnson (1980) make an analogy between two very distinct subjects: **argument** and **war**. The metaphor **argument is war** is made concrete by commonly used phrases such as *attacking a point*, *defending my view*, *winning the argument*, and *OK, shoot!*. These phrases are understood to relate to argument because the **argument is war** metaphor underlies the conceptualization of **argument** in our culture. According to this analogy, the concepts associated with **war** include the concepts of opponents, fighting, loss, ammunition, strategy, etc. Lakoff and Johnson then continue their discussion by introducing the metaphor **argument is a dance**. This metaphor focuses on a different set of associations with the concept **dance**. These include associations among concepts such as cooperation, construction, partnerships, alternating control, and a general recreational theme.

These illustrations are important for three reasons. First, they show that the concept **argument** can be compared analogously to very different ideas such as **dance** and **war**. The meaning of **argument** is reconstructed by each metaphor according to the types of associations existing in the vehicle domain with which it is compared. Secondly, these examples show that analogical comparisons don't need to be explicitly stated to be understood. In fact, it is possible (perhaps even likely) that the reader has used many of the phrases supporting the **argument is war** comparison without having explicitly stated, or consciously recognized, the metaphor itself. Thirdly, these examples show the power of analogical comparisons by showing that we may think and behave according to the underlying metaphor that we use for **argument**. Lakoff and Johnson's work suggests that we would behave differently when arguing if a metaphor such as **argument is a dance** was better supported by metaphorical phrases in our language. In summary, the associations in these analogical comparisons have a powerful role in communicating meaning. They are commonly used in our language, and show great influence on our thoughts, even when they are not be explicitly processed.

The Role of Associations In Analogical Problem-Solving

Although many researchers of analogical problem solving have recognized that the role of associations among concepts is central to the problem-solving process, there is controversy as to the nature of this role (Vosniadou & Ortony, 1990). Alternate proposals about the role of associations in problem solving characterize recent theoretical works by Gentner (1983), Holyoak (1984), and Keane (1988) which are briefly summarized in this section. The complete theories of Gentner, Holyoak, and Keane will be elaborated below, as these views are used to describe a procedural view of analogy processing.

A common research strategy used to investigate the role of associations in analogical problem solving involves presenting subjects with a problem such as the General and then, at about the same time, presenting another similar problem such as the Lightbulb. These are presented below in Table 1. Using stimuli like these, researchers have varied the degree of similarity between the concepts contained in each problem and therefore, between the pattern of associations formed by them. If subjects are able to solve the target problem more easily after being given the solution to the vehicle problem, researchers infer that subjects have recognized the similarity between the two problems. That is, researchers infer that the two problems are psychologically similar in structure, despite their apparent differences.

Different theorists have described the process by which associations among concepts are used in the discovery of analogical solutions to a target problem. These theorists (eg. Gentner, 1983; Keane, 1988) have offered different predictions as to the types of dissimilarities between problems that should be most distracting for subjects. Gentner (1983), for example, refers to the *relations* between objects and claims that these constitute the critical aspects of a problem, not the features of objects themselves. Gentner claims that if these relations correspond between problems, subjects will recognize that the problems are similar, and will apply the solution of one to the other. Gentner claims that the representation of the solution for the vehicle problem initially takes the form of a skeletal network of associations. These associations are assumed to be represented in an abstract form, containing information about the relationships between words without referring to the meaning of the specific objects associated. For example, in the General this structure may include *Object A (army) divides itself into portions, these portions converge on object B (fortress) by advancing along multiple routes through object C (roads)*. This association network is then transferred from the vehicle problem to the target

Table1

Two Typical Problems Used to Investigate Analogical Problem Solving

The General

A general was trying to destroy a fortress which was situated at the centre of a country with roads leading to it, by using his army. He needed to use his army as a complete group in order to destroy the fortress. However, he could not march his army down a road to the fortress because the roads were mined to explode when large groups of men passed over them.

After considerable thought, he knew just what to do. He divided his army up into small groups of men, and by sending these groups, simultaneously, from a number of different directions, they converged on the fortress, making up a sufficiently powerful army to destroy it (Keane, 1988, p. 118).

The Lightbulb Problem

In a physics lab at a major university, a very expensive lightbulb which would emit precisely controlled quantities of light was being used in some experiments. Ruth was the research assistant responsible for operating the sensitive lightbulb. One morning she came into the lab and found to her dismay that the lightbulb no longer worked. She realized that she had forgotten to turn it off the previous night. As a result the light bulb over-heated and the filament inside the bulb had broken into two parts. The surrounding glass bulb was completely sealed, so there was no way to open it. Ruth knew the lightbulb could be repaired if a brief, high-intensity laser beam could be used to fuse the two parts of the filament into one. Furthermore, the lab had the necessary equipment to do the job. However, a high intensity laser beam would also break the glass surrounding the filament. At lower intensities the laser would not break the glass, but neither would it fuse the filament. So it seemed that the lightbulb could not be repaired, and a costly replacement would be required (Holyoak & Koh, 1987, pp. 339-40).

problem in a process Gentner calls "structure mapping". In the problem called the Lightbulb, this network among objects A, B, and C is replicated by a structure of associations among the laser beam, the filament and the glass bulb, respectively. In summary, Gentner believes that the association pattern formed by the objects in the problem is represented in abstract form and is recognized in a new problem when a set of objects within it are associated with each other according to a similar structure.

Holyoak (Gick & Holyoak, 1980, 1983) believes the representation of associations among the concepts in a problem are organized according to the problem's goals, constraints, and resources. In the General problem, for example, the fortress is represented as an associate of the problem's *goals*, the roads and mines are associated with the movement of the army as *constraints*, and the army is represented as an aggressive *resource* capable of organization and fragmentation. Holyoak refers to these organized representations collectively as the problem's *deep structure*. Features not essential to the goals, constraints, or resources available to solve the problem, are called its *surface structure*. Like Gentner, Holyoak believes that the search for a solution to a target problem requires the subject to extract the deep structural features from the problem so that they may be matched to the representation of a similar, vehicle problem in memory. Unlike Gentner, however, Holyoak believes that associations are organized around goals, constraints and resources rather than as a single network of associations.

Keane (1988) rejects Holyoak's view of problem representation. In Keane's view, associations among objects in the target problem cannot be organized according to the goals of the problem, because it is the process of solving the problem that enables the subject to realize the nature of the goals. That is, only during the course of applying solutions retrieved from the memory of previous problems can the subject discover which sub-goals in a problem can be fulfilled, and realize which associations are relevant to these sub-goals. According to

Keane, the subject tests the solution to a previously experienced and structurally similar vehicle problem by attempting to map its associations onto the target problem. If some associations from a previous solution also appear among the objects of the target problem, then they become accepted as part of the solution for the new problem. Keane claims that the mapping process occurs step by step until the associations newly formed in the target problem reveal which sub-goals are attainable. Using the General problem as a vehicle and the Lightbulb problem as a target, the process might begin by mapping the associations between the fortress and the roads in the vehicle problem with the associations between the filament and the glass bulb, respectively, in the target problem. After successful mapping, the system might attempt to extend the mapping of the associations existing in the vehicle domain. This might result in mapping the association between the roads and the army in the General problem to the glass bulb and the laser beams in the Lightbulb problem. Successful mapping of further associations from the vehicle solution continues until some goals of the target problem have been satisfied.

Despite their differences, Gentner, Holyoak and Keane all agree that the discovery of common associations in vehicle and target domains is central to the process of discovering an analogical solution to a target problem. The differences between these theorists tends to lie in the way they believe the associations are represented and transferred between domains. Despite this emphasis on the role of common associations between domains, none of these theorists offer a scheme for categorizing different types of associations. Holyoak's distinction between deep and surface structures is based on their role in forming the problem's solution. His theory, and the others, lack an explanation of how associations might be recognized as similar before their role in the solution is known. I propose that the recognition of similar associations between domains might be based on the ready recognition of particular types of associations, or particular types of object attributes forming these associations.

In this way, a classification system for association types, and an understanding of why some types are more readily processed than others might contribute to the understanding of the solution transfer process. The attainment of these goals provides further motivation for the work undertaken in this thesis.

Summary of First Section

Arguments and examples presented above have attempted to make the case that analogies are important for thinking. Further, it has been argued that the understanding of analogical thought requires a study of the associations among concepts. The conscious, explicit search for similar associations in divergent content domains is central to analogical thought. This is made intuitively obvious through illustrations such as the cell biology/factory floor example, and is supported by the consensus of recent theorists in the field of analogical problem solving. Illustrations of the use of metaphor in language and scientific theory show that these associations are used implicitly as well as explicitly in communication. I suggest that research on analogical thought could now be advanced by asking general questions about the nature of these associations.

The following are the types of questions this research project attempts to answer: What types of associations exist? How are they organized within the cognitive system of a healthy, cognitively mature mind? How are they used to construct association structures such as the types used for problem solving? If some types are more readily available, or more heavily weighted in importance by the cognitive system, which are they, and what principles can be identified to account for this priority system?

The most basic of these questions require an attempt to determine which types of associations are most important to cognition generally. To this end, the task attempted by the next section is to determine what types of associations have been prominent in previous works on word association and in theories of semantic memory.

Section 2.2: Bases For Classifying Associations

The previous section has illustrated the importance of associations in several uses of analogy. The first part of this section reviews previous attempts in the word association literature to distinguish types of word associations. The second part summarizes how two theories of semantic memory make use of association types to account for the organization of long term memory. Both parts illustrate the types of distinctions among associations made by the researchers in this literature. In many cases this work influenced my choices about which association types to use in my analogy problems.

Word Association Studies

Associations between individual words presented outside any syntactic context are perhaps the simplest kind of relationships between concepts in memory. For this reason it seemed appropriate to look at previous attempts to classify word associations in an attempt to identify basic types of associations. The review of the early research on word associations uncovers several attempts to create a typology of responses based on association types, but this work reveals a tendency for each researcher to provide a different scheme of classification. This work highlights the difficulty of the classification problem and illustrates why the choice of association types used in this thesis could not be based on a previously constructed, widely accepted classification scheme.

Studies of word associations published in the late 1800s display the influence of the British Associationists on experimental psychology. Among the earliest attempts to classify free word association responses was that of Cattell and Bryant (1889). The taxonomy of associations suggested by these authors is roughly derived from the then contemporary laws of association: contiguity, similarity and contrast. From their scheme two general distinctions are detailed here. (The full scheme is presented in Appendix A.) The first is between objective and logical associations. This is a distinction between the external, analytic world of parts and wholes of objects (objective types) from the more internal (i.e. mental), taxonomic world of superordinate categories and members of these categories (logical types). Secondly, within both objective and logical associations, Cattell and Bryant identified associations between concepts on the same level of analysis, and associations between concepts from different levels of analysis. Among objective associations, part-part associations use two concepts from the same level, and the whole-part type associates use concepts from different levels. For example *house* may be associated with *garden* (part-part) or *window* (whole-part). The corresponding distinctions among logical association types is between same class, and super/subordinate associations, respectively. In the former, the two concepts are both members of a common superordinate category, whereas the latter type of association is formed when a superordinate concept relates to a subordinate one. For example *house* may be associated with *church* (same class) or *bungalow* (super/subordinate).

These four categories, characterized by two distinctions, are presented here in detail because they comprise an early scheme for organizing associations which re-appeared in several other works throughout the subsequent three decades. Furthermore, these distinctions were incorporated directly in the materials used in my thesis.

Carl Jung (1904/1918) offered a classification scheme that distinguished 18 types of associations (see Appendix B for the complete list). To the four association types described above in Cattell and Bryant's work, Jung added other types including contrast (antonyms), identity (synonyms) and causality. These seemed to identify basic types of semantic relationships and they were adopted as association types used in the pilot work of this thesis. Jung also included several language based associations, such as word compounding (house-coat), and sound associations (cheap-beep). While these additions were especially relevant to Jung's use of word associations for diagnosing the mentally disturbed, they also occurred frequently among the responses of Jung's other healthy subjects. A deliberate decision was made not to include such associations in the stimuli of this thesis because it was thought that including associations based on grammatical relations or sound similarities would distract subjects' attention from the more semanticly oriented association types used. Since this thesis sought to explore the relative difficulty of semantic associations, language based associations were excluded with the rationale that they merely presented a potential source of noise to the data.

Wells (1911) introduced controversy to these early attempts to form classification schemes. He proposed a scheme that reduced Jung's 18 associations into five super-classes, claiming that Jung's scheme was unworkable, and that his simpler version created an acceptable level of reliability among scorers who classified association responses. (This reorganization of Jung's scheme is provided in Appendix B.) While Wells claimed that the categories he advocated (subject-predicate, supraordinate, contrast, and speech habits) produced the most reliable response classifications, one of his five categories was a miscellaneous category. In this category he included many association types that Jung, and Cattell and Bryant had found important to distinguish, including causality, subordination, identity (synonyms), coordination (part-part), and coexistence (whole-part).

Wells' reluctance to distinguish among many of the types proposed by Jung, and by Cattell and Bryant was partially overcome later that same year, however, in a monograph on association tests by Woodworth and Wells (1911). This paper enumerates nine standardized association tests designed to study individuals' ability to produce associations of certain types. These assessed subjects' mental alertness, and the normality of the responses they produce. The tests chosen by these authors were those for which twenty test words could be found that were unambiguously interpreted and easily responded to by pilot subjects. The list of tests consists of i) the supraordinate test (where the term **oak** would elicit the correct response **tree**), ii) the subordinate test, iii) the part-whole test (**elbow-arm**), iv) the whole-part test, v) the agent-action test (**baby-cries**), vi) the action-agent test, vii) the opposites test (**long-short**), viii) the verb-object test (**sing-song**), and ix) the attribute-substance test (**sharp-knife**). Since this set of associations was based on the different types that Wells found subjects could reliably interpret it seemed a particularly good guide for choosing types to use for my stimuli. Wells' work acknowledged whole-part, opposites, and supraordinate associations as distinct types, as well as three other object types that refer to objects and their actions or attributes (verb-object, attribute-substance, and action-agent). These six types were all used in my pilot stimuli.

Wells (1911) also raised two issues relevant to my work. First, his work distinguished between association categories that can be used explicitly to classify responses, and those that can be reliably interpreted and used by subjects for the purpose of providing a response. This distinction foreshadows an issue that becomes relevant to my experiments: the possibility that subjects may be able to use some association types without being able to explicitly distinguish between them. Secondly, Wells (1911a) reports that language based associations, such as those cited in Jung's work, accounted for roughly 15 percent of subjects' responses. Furthermore, Wells believed that this incidence would be higher if not for the tendency of subjects to suppress these types of responses. Wells' intuition that these types of associations are common and relatively immediate in subjects' cognitive systems suggests that analogy problems using these language based associations may be very quickly solved. The association types used in my analogy problems were chosen to present subjects with different cognitive demands, with the expectation that this would be reflected in the resulting solution latencies. It is therefore noteworthy that language based associations were omitted in my work; it is possible that association types based on grammar or word sounds would have produced the most immediate responses in my paradigms.

Just five years later, a study by Woodrow and Lowell (1916) provided empirical evidence for additional distinctions among association types by producing a list of types that appeared with different frequency in the responses of children and adults. Associations used more frequently by children than adults included verb-object, noun-adjective, adjective-noun, pronouns, sound similarity, contiguity (eg. **needle-thread**), whole-part, subordination and word compounding. Those used more frequently by adults than children were contrast, superordination, coordination (same class), part-whole, noun-abstract attribute, participles (eg. **chair-sitting**), and cause and effect. This evidence suggests that the order of acquisitions of cognitive and language abilities may account for some of the variability in subject's proficiency with different association types. In this thesis the inclusion of analogy types varying on the functional/structural dimension was meant to provide an initial exploration of these types in the context of analogy problems.

The work undertaken on word association responses has mushroomed in the post war years to the point where reviews now fill entire volumes (e.g. Cramer, 1968; Esper, 1973). While these volumes indicate that theoretical notions about association structures have been further investigated, they are unable to report any consensus regarding classification schemes. For example, Cofer (1971), who reviewed the literature, concluded:

> Such classifications . . . imply bases for organization or for the structure of associations. This is to say, for example, that if a large proportion of all word associations can be classified as definitions or coordinates of stimulus words, whatever psychological processes lie behind definition or coordination would be the foundation for the way associations are organized and for the occurrence of these kinds of responses in association tests. Further, if people differed in which kind of association is dominant . . . then association test behavior

> may represent different associative, or, even, "mental", organizations the implications of which could be sought in other situations and tasks. Unfortunately, relatively little has been accomplished along these lines. Most of the classifications proposed have been based on logical analyses of the relations between stimuli and their responses but have gone little further. (p.p. 877-878)

Thus, after years of research on associations, the need still exists for a coherent and psychologically real classification scheme. While statements like Cofer's regarding the status of research on associations reveals a need for research on this problem, it also highlights the difficulty of deciding on a base of analogy types with which to conduct these investigations. The choice of association types used for my work was guided by the distinctions appearing in previous word association studies like those described above. The second area of research which provided input for my choice of stimuli was theoretical work on the nature of semantic memory. The types of associations prominent in this work will be now be described through the brief discussion of two theories.

The Role Of Associations In The Organization Of Semantic Memory: Two Theories

The two theories discussed here have some important characteristics in common. Both describe the structure of semantic memory as it influences subjects' ability to perform simple sentence verification tasks. In doing so, both emphasize how associations between concepts contribute to the meaning of those concepts. A brief overview of these theories shows how they use associations to model memory representations of concepts, and illustrates which association types the authors of these theories consider important in these models.

Collins and Quillian's Teachable Language Comprehender

Collins and Quillian's (1969) hierarchical network model of semantic memory posits a network of concepts where each concept is represented as a node in the network, and nodes are connected to each other by relational links, or associations. The principle type of association that Collins and Quillian propose for organizing this network is super/subordinate associations, based on a system of structures like those used by Rosch (1975) to classify natural kinds. For example, a piece of this associative network represents **trout** by an association with the superordinate concept **fish**. The concept **trout** is, in turn, superordinate to concepts such as **rainbow trout**, **lake trout**, etc. This piece of the association network is ultimately connected to others like the associations connecting the concept **plants** to **flowers**, and **flowers** to **tulip**, but only does so through the relatively remote, highly superordinate concept **living things**. In Collins and Quillian's theory these taxonomic links are referred to as ISA associations because the association signifies that one concept ISA member of the class defined by the other concept. In addition to ISA associations, Collins and Quillian describe HASA associations which refer to the link between objects and their attributes, features or functions.

Collins and Quillian's theory is designed to account for the decision time required to verify the truth of sentences such as **a trout is a fish**, and statements about the properties of objects such as **a trout has scales**, and **a trout swims**. According to this model, the speed with which the truth of an ISA statement such as **a trout is a fish** can be verified is determined by the length of the path connecting the two concepts (i.e. **trout** and **fish**) within the memory network. That is, the fewer intermediate nodes that are passed through to connect the two concepts the faster the verification will be. In the case of **a trout is a fish**, the verification time is relatively fast because the link is direct. In contrast, deciding that **a trout is an animal** should require more time because the link between **trout** and **animal** in the hierarchical association network includes the link between **trout** and **fish** as well as the link between **fish** and **animal**.

Thus, this model describes an important role for superordinate associations in storing the meaning of a concept like **trout** in memory. Furthermore, this work also provides theoretical support for the idea that an association between two concepts in the same taxonomic class, (such as **trout** and **salmon**) should be more difficult to process than an association between two concepts related hierarchically (such as **trout** and **fish**). This is because same class associations are made up of at least two vertical, hierarchical connections. For example, the association between **trout** and **salmon** is made up of the two links: **trout-fish** and **salmon-fish** (see Figure 2). Thus, the activation between these concepts requires more time to spread and connect, than in the case of a super/subordinate association which could consist of just one of these links. This distinction between same class and super/subordinate associations, and the processing difference just outlined forms the basis of the inclusiveness hypothesis tested in the experimental work of this thesis: noninclusive analogy types (like same class) are expected to take longer to solve than inclusive ones (like super/subordinate).

Collins and Quillian also measured verification times for statements based on relationships they called HASA associations, and again found faster verification times for more proximal concepts in the network. That is, phrases such as "a fish has scales" were confirmed more quickly than "a fish has eyes" because **scales** are associated to **fish** directly, whereas the association between **trout** and **eyes** occurs only at the more distant **animal** concept node. Thus, the importance of part-whole associations are also acknowledged by this theory, since these are in essence the HASA associations used by Collins and Quillian.

In summary, this work confirms two distinctions made by Cattell and Bryant (1889) among association types. ISA and HASA associations bear a close resemblance to their first distinction between logical and objective associations, respectively, and the processing differences between super/subordinate and same class associations was also proposed in this earlier work. Notably, Collins and Quillian's research confirms these distinctions in a second research area:

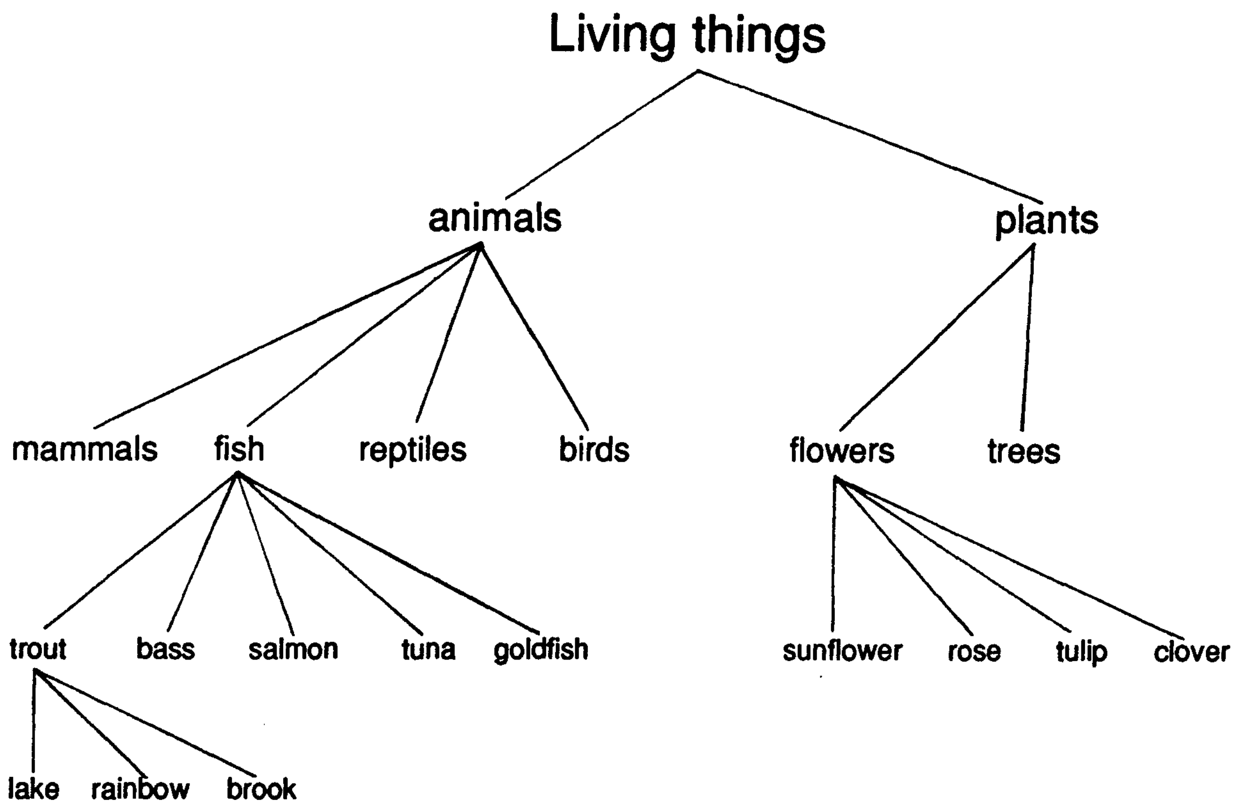


Figure 2. Schematic model based on Collins and Quillian's theory of semantic memory.

semantic memory.

In addition to the experimental results of the sentence verification studies, Collins and Quillian's theory also provides a schematic model for illustrating the structure of semantic memory. Two observations about this hierarchical structure are noted here because they are used later in the thesis to justify empirical hypotheses. The first observation is that less general categories (i.e. those lower in the hierarchy) have fewer subordinates. For example, in Figure 2 fewer items are classified under the term **salmon** than the term **fish**. This property will be later cited as an explanation of why memory search for a member of a specific group is expected to be faster than the search for an item in a less precisely specified category. The second observation is that, except for the most specific items, most items in semantic memory have fewer superordinate associates (i.e. above it in the hierarchy) than subordinate associates. For example, in Figure 2 **fish** has only **animal** and **living things** as superordinate associates, but has many more subordinate associates. This observation will be later used to justify the claim that a superordinate associate should be more readily elicited than a subordinate one.

Smith, Shoben and Rips' Computational Model

In work using a similar sentence verification paradigm, Smith, Shoben and Rips (1974) confirmed the importance of ISA and HASA associations and produced evidence that other attributes of the concepts judged in these sentences also influenced the speed with which subjects could make verification judgements. These authors found that sentence verification latencies varied according to the typicality of an item within its superordinate category. For example, "a collie ISA dog" was more quickly verified than "a pekinese ISA dog". To Smith, Shoben and Rips this effect of typicality on speed of processing suggested that some additional properties of HASA associations were influencing latencies on this ISA sentence verification task.

In their theory, an object is represented as a list of features, some of which are necessary, defining features of the object. For example, the list for the concept **bird** might include the defining feature **lays eggs**, as well as the highly associated, but not defining feature **migrates in winter**. Their model makes use of this distinction between defining and nondefining features in the sentence verification process. If the sentence to be verified involves an atypical member of a category, or is an otherwise unclear case, the similarity of the two concepts is judged by determining whether the set of defining features for one object exist in the other. For example, the verification of **an ostrich ISA bird** is an unclear case which requires this type of comparison because ostriches have some prominent features not shared by many species of birds, such as their size and flightlessness. In this case, the sentence would be verified however, because the defining features of **bird** are present in **ostrich.** That is, ostriches have feathers and a beak, they lay eggs, and they nest.

Like Collins and Quillian's model this feature computational model acknowledges the importance of whole-part associations to explain sentence verifications based on super/subordinate associations, and in doing so acknowledges the importance of this association in semantic memory. As in Collins and Qullian's model, these HASA associations comprise a rather heterogeneous set, including whole-part, object-action and object-characteristic types. However, the distinction between defining and nondefining associations in the computational model makes this heterogeneity more notable in this model because the different associations within this set have different effects on the verification speed for a particular sentence. Although Smith, Shoben and Rips do not account for the relative importance of an associated feature according to its association type (eg. object-action vs. whole-part) per se, it is clear that different types of associated features are defining for different types of concepts. It is also clear that this componential model would benefit from the development of a typology of associations, and an understanding of which association types are preferentially processed by the cognitive system.

Summary Of Second Section

The word association literature contains many suggested schemes for classifying associations. The most compelling and recurring distinctions among associations were introduced by Cattell and Bryant (1889). Their distinction between objective and logical associations, exemplified by the difference between whole-part and super/subordinate associations respectively, recurred in the word association literature, and was identified as the HASA--ISA distinction in Collins and Quillian's theory of semantic memory. A second distinction was introduced by these authors between associations that relate concepts at the same level of analysis and those that relate concepts from different levels. Part-whole and super/subordinate types associate concepts from different levels as one concept is included as part of, or a member of, the other. Concepts associated by part-part and same class association types exist at the same level of analysis either within an object, or within a superordinate category. These two distinctions, also appeared in the review of semantic memory theory, comprise the initial basis for the typology proposed in this thesis.

Other potential categories of associations have been identified. Many of these were included in the pilot stimuli of this thesis. Types of associations that an object forms with its action, characteristic or purpose, have appeared in the word association literature and are used in semantic memory theories. These were studied in the pilot experiments and became represented by object-action analogies in the final stimulus set. Associations based on causality, sequencing, symbolic representation, synonymy and antonymy were also included in pilot work. A deliberate decision not to include associations based on grammatical structure or sound similarities was made early in the design of stimuli. This eliminated several association types presented by Jung and others in the word association literature, such as noun-adjective, noun-verb, clang associations (eg.

"buzz"-"fuzz"), and phrase completions (eg. "mountain"-"top").

A final distinction among associations used in the empirical work of this thesis is specificity. This distinction was not identified in the word association literature; it originates from the problem-solving literature. In the next chapter, some of the extant literature on problem solving will be reviewed. This review will trace theoretical views about the use of semantic cues during the process of solving problems and will also present the theoretical background to explain the specificity distinction.

CHAPTER THREE: THEORETICAL MODELS OF ANALOGICAL PROCESSING

Overview

The present chapter reviews the work of three researchers who focus on analogical problem solving and have offered recent theoretical accounts of analogical thinking. It does this in three sections. The first section reviews the theories of Gentner (1983), Holyoak (1984) and Keane (1988) in an attempt to document the development of a procedural view of analogy processing that I believe characterizes Keane's theory.

The second section of this chapter reports attempts from artificial intelligence research to account for the cognitive processing involved in analogical thinking. It presents the argument that the artificial intelligence research and Keane's research can be best accommodated by a procedural view of cognitive processing.

The third section of this chapter presents Sternberg's model for processing four word analogy problems. His model is made up of several components that I have modified to explain subjects' performance in my experiments. The final goal of this chapter is to present my modified componential model and to supplement it with a procedural model of processing to account for some of the findings from my research. This model is presented at the end of the chapter.

Section 3.1: Three Theories of Practical Problem-Solving

This section reviews the theories of Gentner (1983), Holyoak (1984) and Keane (1988) in turn. This presentation documents an evolution toward a processing theory proposed by Keane, which I believe is best viewed as a procedural theory. Two trends underlie this progression, and contribute to this assertion. The first trend concerns the type of mechanism each of these theories uses to explain the transfer of information from vehicle to target domains. Gentner describes mapping as a process that occurs when a pattern of associations representing the whole vehicle problem is applied to the target problem. Keane views mapping as a more piecemeal transfer of the association network to the target problem. His model describes a series of comparisons between vehicle and target problems during the process of discovering the associations making up the solution, and the process of transferring them to the target problem. Thus, the difference between these models shows the trend from holistic mapping to step-by-step processing.

The second trend among these theories is related to the first; it concerns the importance of specific object attributes as cues for recognizing corresponding objects between domains. This trend is perhaps a necessary by-product of the tendancy of recent theories (eg. Keane, 1988) to describe mapping as a step-by-step process.

Before my discussion of these theories is presented, it is important to note that my review of these theories purposely emphasizes the differences among these theorists views. This has been made easier by selecting particular versions of Gentner's and Holyoak's work to review. For both these theorists more recent versions of their thinking exist (see Gentner, 1989, and Holyoak & Thagard, 1989a, b), and in both cases these newer works expand upon processing procedures in addition to the more structural bases of theory described in their earlier works. Thus, the progression of theory I discuss is not intended to provide a comprehensive review of theory in the domain of analogy problem solving. Rather, it is a description of contrasting theoretical orientations selected purposely to illustrate the theoretical trends I wish to emphasize.

Gentner's Theory

In explaining how subjects identify a pattern of similar associations between two distinct content areas, Gentner (1983; Gentner & Toupin, 1986) relies heavily on what may be regarded as a structure extraction mechanism. This mechanism presupposes a distinction between *features* and *relations.* (These are Gentner's terms: they correspond to *attributes* and *associations*, respectively, in the terms I use in this thesis.) Features are semantic statements that require only one argument. For example, the feature *large* requires only one syntactic argument, as in the statement *large box.* Relations are semantic statements that require two syntactic arguments, such as the relation *trapped* which requires the identification of something trapped and something doing the trapping, as in the statement *the chick was trapped in the box.* Gentner's structure extraction mechanism operates by first encoding the relations among objects in the initial content area. Little information about the objects' attributes is encoded. For example, the scenario *A mother hen was looking everywhere for her chick, but the chick was trapped in a large box it had fallen into* might be encoded as *X seeks Y, Y is in Z.* This pattern of relations is then compared to a target problem. If this same pattern can be found among objects in the target problem, the comparison will lead subjects to realize the analogous structure between them, independent of the nature of the objects themselves.

Gentner elaborates that the degree to which these associations in the initial content domain are inter-connected determines whether they get encoded for later matching. A semantic statement is more likely to be encoded and later transferred if it belongs to a pattern of information made up of many pieces that are highly associated with each other. Patterns among associations may result from their common relationship to a particular theme or purpose within a story. Gentner refers to this characteristic of information patterning as "systematicity". Less cohesive stories are made up of relatively isolated events and facts, and are said to lack systematicity.

Gentner and Toupin (1986) tested the effect of systematicity with children, using a story-telling paradigm. In one condition children were shown three puppet characters acting out a story in a high systematicity condition where the story concluded with a thematic summary (the moral of the story) designed to draw cohesive associations among the events in the story. In a second, low systematicity condition no such summary was included. After watching the puppet play, subjects were instructed to act out the story with a different set of characters. The ability of subjects to accurately recreate the story was measured as an indication of how well the story line had been remembered and transferred to the new characters under these two conditions of systematicity.

This study also manipulated the degree of similarity between the set of puppet characters the subjects watched in the initial play, and the characters they used to re-create the story. To manipulate this type of similarity, three conditions were tested in which the set of characters provided for the re-creation were different from the characters in the original play. To illustrate, consider a play using a duck, a donkey, and a squirrel introduced as characters in this order. Under the three manipulations of this experiment children were asked to re-create the story with characters which were i) each physically similar to their corresponding character in the initial play (eg. using a chicken, a horse and a chipmunk), ii) each much different from the characters in the initial play (eg. using a rabbit, a fox and a bear), or iii) each similar to the characters used in the initial play but cast in noncorresponding roles (eg. using a chipmunk, a chicken and a horse, introduced in this order).

Results showed that the ability of children to recall these patterns of information (the story lines) and use them to re-enact the stories was enhanced when the story was presented in the high systematicity condition and when the two casts of characters were similar. The magnitude of these effects interacted with the age of the subjects, however. Four to six year old children were less able to repeat the story accurately than 8 to 10 year olds, and the older subjects were more aided by the presentation of the thematic summary. The results of the three similarity conditions showed that the condition where characters were similar to those in the original story produced the most accurate re-enactments, while the different characters, and the noncorresponding characters provided increased difficulty for subjects.

Gentner demonstrated that children more successfully transferred the stories for which the moral was included (i.e. the high systematicity condition). Although this study did not vary the similarity of the two story lines between specificity conditions, this manipulation demonstrates that when subjects are provided with a statement of the moral to a story, it serves as a mnemonic device enabling a more specific replication of that story. This result supports Gentner's central theoretical claim that the transfer of associations occurs via a holistic, integrated pattern formed as an abstract representation of the original story.

Gentner and Toupin's demonstration of the effect of object similarity between domains on children's ability to recreate the story is also convincing, but the process by which this similarity affects this ability is more controversial. In the discussion of their results the authors emphasize the detrimental effect of presenting similar characters in noncorresponding roles between the two stories, rather than the beneficial effect of presenting similar characters in corresponding roles. Gentner and Toupin conclude that mapping occurs most efficiently when the attributes of the objects involved don't distract subjects processing of the association patterns in the two stories. Such an explanation emphasizes Gentner's thesis that successful analogical transfer requires only the association pattern to be similar between the two stories, not the objects themselves.

Gentner and Gentner (1983), found further evidence to support Gentner's claim that subjects are predisposed to transfer patterns of associations between domains in a holistic form. They studied subjects' transfer of solutions between problems and found a tendency among subjects to also transfer other associations not central to the solution. Specificly, this work compared the effects of subjects' different knowledge of two models of electricity on their understanding of electricity concepts. The experiment used one analogy between reservoir hydraulics (flowing waters) and the electrical output of parallel and serial batteries, and a second analogy between crowd movement (teeming crowds) and the behavior of parallel and serial resisters. According to the hydraulics metaphor, electrical current resembles reservoirs of water which increase flow when the pressure from two bodies of water are added serially, but are unaffected when they are added in parallel. In contrast, the teeming crowds analogy describes electrical current as a set of bodies moving in a flow that is increasingly disrupted by the addition of serial gates, but generates more flow if these gates occur in parallel. These models are best suited to explain the effects of batteries and resisters, respectively, and don't apply well to the alternate phenomena. That is, batteries increase the electrical flow when arranged in serial; resisters increase flow when arranged in parallel.

The difference between these two analogies led Gentner to predict that each would aid subjects' understanding of one electrical phenomena and impede their understanding of the other. This expectation was confirmed by the nature of subjects' errors in attempting to predict the output of different electrical systems, and by their spontaneous use of these analogies to explain their faulty predictions. For example, subjects who had acquired an understanding of the "flowing waters" metaphor for electrical forces performed consistently poorly on a simple test of parallel and serial resisters which required them to quantify the net effect of the resistance. An opposite interference effect occurred for the "teeming crowds" thinkers on a test for parallel and serial batteries.

Another study by Gentner and Gentner (1983) replicated these findings with subjects who were initially naive with regard to these electricity analogies. After teaching subjects about one of the analogies, the authors found that subjects spontaneously over-extend them to incorrect domains (i.e. from reasoning about batteries to reasoning about resisters, or vice versa). Gentner and Gentner (1983) claim that this extension to unfamiliar problems occurs because the objects contained in the vehicle problems are arranged in an association pattern similar to those in the target problem. Even though the objects themselves (batteries or resisters) are not similar between vehicle and target, Gentner and Gentner explain that this inappropriate transfer results because the process of analogical transfer is based on these association patterns.

To summarize, in Gentner's (1983) theory the pattern of associations among objects forms the representation of the problem used for analogical transfer; the attributes of objects themselves have little role in this. Gentner's process of "structure mapping" involves transferring this pattern of content-free associations from the vehicle problem to the target problem. This pattern of associations is represented as a holistic, integrated map and is transferred in one step, rather than as a series of smaller processes.

Holyoak's Theory

Like Gentner, Holyoak (Gick & Holyoak, 1980, 1983; Holyoak, 1984) believes that the process of making an analogical comparison between problems requires them to be represented in abstract form. According to Holyoak this representation consists of a set of propositions each composed of two or more concepts and the relations (associations) among them. Holyoak acknowledges that the propositions of a problem can be represented at various levels of abstraction where each level represents the objects and relations in varying degrees of detail. For example, the proposition cited above regarding the mother hen might be encoded very abstractly as *X seeks Y, Y is in Z*, or at a more intermediate level of abstraction as *parent seeks offspring, offspring is in container*. Holyoak does not specify the amount of detail contained at the optimal level of abstraction used for problem solving, but explains that the information contained in analogous propositions is used to match a second domain according to the similarity between their corresponding relations. Holyoak explains that this matching process is also guided by the organization of these propositions within the representation of a problem. They are organized according to its goals, resources, constraints, solution plan and outcomes. Holyoak calls this organized, abstract representation of propositions as the *deep structure* of the problem.

Holyoak proposes that the search for an analogical solution to a target problem begins when the subject accesses the deep structure of other problems stored in memory and compares them to the deep structure of the target problem. If a portion of the propositions representing the target problem match the representation of another problem at this abstract level, that problem is selected as a vehicle. Although Holyoak does not propose that any particular propositions in the deep structure are necessary or sufficient to determine a match, the goals of the problem clearly play a major role in organizing the representation of the deep structure of problems (Gick & Holyoak, 1983). Once the system finds some initial degree of match between the target's deep structure and that of a previously experienced vehicle problem, it attempts to map additional propositions, and additional details about the initially matched propositions, from the vehicle to the target. This mapping is directed by a top-down process based on the subject's knowledge as to which details of the vehicle domain are relevant to the solution and which need to match in the target domain (Gick & Holyoak, 1980). If the mapping of these details is successful, the solution from the vehicle problem will be realized in the target problem as the subject becomes aware of the actual objects and associations making up the solution in the target problem.

Holyoak has examined his model in experiments where a solution to a target problem is made available to the subject via a related problem and its solution (Gick & Holyoak, 1980, 1983). The Lightbulb and the General problems presented in Table 1 have been used by Holyoak, and so provide a handy illustration of his model. Consider an experimental procedure where subjects have previously been exposed to the General problem and its solution and are later presented with the Lightbulb problem. In the General problem the central goal is to use an army to capture forces; in the Lightbulb problem the central goal is to use lasers to repair a filament. At the initial stage of the solution process these goals might be represented and matched in the more abstract form *use force to overcome a central target*. The central constraint in the two problems, might be represented as *an inability to apply full force along one path safely* (Holyoak, 1985). Since the representations of the constraints and goals in the two problems match, the General problem is recognized from memory as a potential vehicle for the Lightbulb problem. The solution to the General problem is then retrieved and applied to the Lightbulb problem. This initially occurs as an abstract form of the solution, perhaps represented as *apply weak forces along multiple paths simultaneously*. Some elaborations of the solution are required before it can be applied in the *surface structure* of the target problem as *heat the filament by directing the laser from different parts of the bulb*. This application of this surface structure will also require some top-down elaboration of the target domain in order to discover, for example, that several laser machines may be used, or that the bulb might be rotated in front of the laser to create the desired effect.

Holyoak's theoretical claim that problems and their solutions are understood at a deep structure level motivated the following study using children as subjects, and problems comprised of real objects. Holyoak, Junn and Billman (1984) showed four year old children a television puppet character (Miss Piggy) who rolled a carpet into the shape of a tube in order to transport (roll) sphere-shaped jewels from a box into a safe. The children were subsequently placed in an analogous situation where they were asked to transport several balls from one container into another. In the target situation, the children were unable to reach the second container unaided, but were provided with several objects, including a flat piece of paper which could be rolled up and used to transport the objects in the way modelled by Miss Piggy. The goal of the study was to test whether children would recognize the similarities in the deep structures of the puppet problem and the ball problem. Seven of the twelve children who were provided with the puppet demonstration discovered the analogous solution. In contrast, this occurred for none of the children in a control condition who had not been primed with the puppet demonstration. The four year olds who viewed the puppet were successful, in spite of the different objects to be rolled up in the two scenarios (carpet on the floor, paper on the table), and different objects to be transported (jewels, balls). Holyoak (1984) claims that these children's success illustrates their successful mapping of the solution at the level of deep structure.

Holyoak and Koh (1987) investigated the relative influence of similarities in surface structure, and similarities in deep structure on analogical transfer between problems. Their study used a paradigm where adult subjects were initially familiarized with the Radiation problem and its solution (see Table 2), and were then asked to solve the Lightbulb problem. Two independent variables were manipulated by changing the context of the stories. The first manipulation changed a surface feature by changing the tool presented to repair the lightbulb filament.

In the high similarity condition of this surface feature manipulation a laser machine was used because it is similar to the X-ray machine from the Radiation problem. In the condition presenting low surface feature similarity, a tool less similar to the X-ray machine was used: an ultrasound device. Secondly, the nature of the inadequacy of the tools was manipulated in order to alter the similarity of the deep structure of the problems. In one condition the glass in the bulb was too fragile to withstand the necessary force, and in the other the machine (laser or ultrasound) was not powerful enough to repair the filament.

Table 2

The Radiation Problem And Its Solution

The Radiation problem

Suppose a patient has an inoperable stomach tumor. There are certain rays which can destroy this tumor if their intensity is large enough. At this intensity, however, the rays will also destroy the healthy tissue which surrounds the tumor (e.g., the stomach walls, the abdominal muscles, and so on). How can one destroy the tumor without damaging the healthy tissue through which the rays must travel on their way?

Solution

Several weak rays are sent from various points outside so they will meet at the tumor site. There the radiation of the rays will be intense, for all the effects will summate at this point. But since they are individually weak, the rays will not damage the healthy tissue that surrounds the tumor (Dunker, 1945, as cited in Gleitman, 1986, p. 271).

This created one condition where the two stories had very similar deep structures regarding the constraints of the two problems (i.e. the fragile bulb was similar to the vulnerable healthy tissue in the Radiation problem), and a second condition where the stories had dissimilar constraints (i.e. the inadequate machine vs vulnerable healthy tissue). Results showed that decreasing surface similarity (i.e. changing the type of machine used) decreased subjects' ability to initially recognize the analogous pattern between the two stories. The deep structure differences were also found to retard subjects' ability to recognize analogous relationships between problems. Furthermore, the deep structure manipulation prevented subjects from discovering the analogous relationship between the two stories even when they were told that the vehicle problem contained information relevant to the target problem. These results confirmed Holyoak's view that the effect of deep structure similarities between problems can be distinguished from that of the surface structure similarities, and that the former is a more powerful influence on the process of problem solving.

In summary, Holyoak believes surface features are less extensively processed by the subject, and for this reason have less influence on subjects attempts to solve problems analogically. Like Gentner, Holyoak believes that the problem representation used for mapping (the deep structure) is abstract, and free from the surface details of the actual objects involved. Unlike Gentner, however, he believes that the problem is not represented as a holistic blueprint for mapping, but is instead organized into several critical substructures of the problem (goals, constraints, etc.). These are used to recognize similar problems in memory by helping to identify propositions in common between the two domains. This view represents a theoretical shift away from modelling the mapping process as a holistic, all-or-none activity.

This shift becomes even more pronounced in the next theory to be outlined. The highly piecemeal manner by which this transferring of the solution structure occurs in Keane's theory will now be described.

Keane's Theory

Keane's (1985, 1988) theory is described here in some detail. In his theory the problem representation used by subjects to transfer a solution contains much detail about the objects involved, and is transferred in a gradual, step-by step fashion. In this regard, I believe Keane's theory is the most advanced in a trend established by the earlier theories of Gentner and Holyoak, and offers the most detailed account of analogical thinking of the three theories described in this chapter. This theory will be presented in detail primarily because Keane's theoretical account of analogical transfer is later used to explain the processing of some aspects of my four word analogy problems. After Keane's theory is described as one that readily lends itself to a procedural view of cognitive processing, it will be compared to the work of Anderson (1976, 1983) and others who have also made theoretical contributions to the understanding of analogical problem solving which are amenable to the procedural view of processing I wish to promote.

Description Of The Model

Keane's (1985, 1987,1988) solution generation theory is driven by a fundamental assumption about how problems are represented. Keane contends that the representation of a problem, and hence the strategy for finding its solution, depends critically on the purpose that the subject has for encoding it. According to Keane (1988), the problem's goal is often chosen by the subject from among conflicting demands. For example, in the Radiation problem two goals are possible: i) to attack the tumor and ii) to preserve the healthy tissue. The subject may choose to satisfy both of these goals or to emphasize one at the expense of the other. The selection of a goal has many implications for later processing, but critical among them is the fact that the goal will determine which objects are the focus of processing, both during the original encoding of the target problem, and during the search for a vehicle problem.

The earliest stage of processing where the system is influenced by the subject's choice of goals occurs when the vehicle is selected from memory. Keane (1985) believes that problems are initially represented in a very abstract form, as a general schema. A schema is theme oriented, and represents the gist of a story or problem in a simple pattern such as the proverb *never judge a book by its cover*. In order to match stories or problems by their schema, the objects in these stories are analyzed according to their grammatical case relations in order to identify the instrument, the object of action, the agent, etc. Keane describes the schema for the Lightbulb problem and the General problem with the label *Conflicting Goals: Means Blockage*, and this schema, like any other, requires a particular set of objects, instruments, and agents. Thus, subsequent stories or problems whose objects fit the grammatical pattern represented by *Conflicting Goals: Means Blockage* will be matched to the Lightbulb problem or the General problem in memory, and will activate these as vehicles. Once this initial selection has been made, the rest of the solution generation process unfolds according to a very well defined procedure based on a series of five stages (Keane, 1985).

The first stage Keane calls goal orientation. In addition to affecting the choice of vehicles as explained above, the activity in this stage directs two other orienting activities. One of these is the determination of which object is most critical to the problem, and which of its attributes is the most functionally relevant. The identification of this object provides a starting point for the mapping of other objects and associations related to it. For example, in the case of the Radiation problem, the critical object is the rays because they are most instrumental to the goals of the problem. The functionally relevant attribute of this object is its destructive force, since this is the attribute that allows the rays to attain the goal. The second of the orienting activities is the identification of other objects in the target problem that are most relevant to the goal. The selection of these objects is based on their grammatical case relations (i.e. agent, instrument, object) to the critical object and the goal. Thus, the purpose of this first processing stage is to identify corresponding objects between problems, and other objects closely associated with them. From this first stage of goal orientation, the focus of processing shifts to the vehicle problem in the second stage.

The second stage of the solution generation process involves the identification of parallel objects in the vehicle problem. These are objects that have corresponding roles with objects identified during the first stage, in the target problem. The search for parallel objects begins with a search for a parallel to the critical object, and to the other objects closely associated with it. Thus, since the rays are parallel to the critical object in the target problem (army), this object, and highly associated objects such as the glass bulb and the filament, are first to be identified when the Lightbulb problem is retrieved as a potential vehicle. These objects are referred to as base objects.

The third stage involves the transfer of associations and attributes of the base objects found in the vehicle problem, to the critical objects of the target problem to determine if these structures can be formed in the target problem. Keane (1988) is explicit about the sequential, step-by-step nature of this transfer process. He explains that, "Firstly, it is assumed that the relations predicating the critical object(s) are likely to be important, so these are mapped one-by-one in a sequential fashion" (p 79). He further assumes that if a particular association is successfully mapped to the target problem, "the causal relations connecting this relation to others are used to identify other potentially-valid relations. If another such relation is found to be valid, then the causal relation connecting the two is transferred as well" (p 79). Thus, this mapping occurs sequentially, according to an order highly prescribed by the relative importance of the objects involved. Keane uses the term *local systematicity* to describe the direction provided for the mapping process by the pattern of associations among these critical objects, and contrasts it with Gentner's *global systematicity*.

If associations similar to those in the vehicle problem can be realized among the objects in the target problem, these associations are then evaluated to determine if they constitute an advancement toward the goals. This constitutes the fourth stage, called evaluation. This evaluation is necessary because the choice of which associations and attributes are mapped back to the target is directed by the subject's memory for details about the base objects in the vehicle domain. Since semantic details about these objects which are not directly pertinent to the solution may exist in memory, the mapping process may frequently produce new associations in the target domain which are irrelevant to the solution and must therefore be purged at the evaluation stage (Keane, 1985).

If this process of applying associations from the vehicle is judged to result in an advancement toward the goals in the target problem, the fifth stage, called elaboration, takes place. This consists of the subject's expression of the solution in the target domain. Elaboration may take the form of verbal statements or mathematical formulae, and at this stage of processing may highlight details about the target problem that have no counterpart in the vehicle problem from which the solution was generated.

To summarize, Keane's (1985, 1988) theory represents the most refined of the three theoretical views presented, according to the two trends identified at the outset of this section: i) the trend toward a step-by step mapping procedure, and ii) the related trend toward including specific object attributes in the representation of problems. Keane does not rely on a holistic pattern of associations represented in an abstract form to explain how solution-relevant associations are discovered in the vehicle problem and transferred to the target. Rather, his solution generation process is based on a series of steps where relevant objects are identified, and their associations are mapped. Keane's solution generation process is driven by the specific details of the objects in the problems, not just the abstract associations among them. Moreover, Keane's theory provides the possibility that attributes or associations not directly implicated in the final solution might never-the-less be processed during the generation of the solution. This possibility exists because the identification of parallel objects in the vehicle domain, and the transfer of associations between domains is greatly influenced by the specific features of the actual objects in the two problems.

The step-by step nature of mapping, and the focus on specific features of objects shared by two problems allow Keane to assimilate Holyoak's distinction between surface structure and deep structure. While Keane explains that priority is given to attributes functionally relevant to the goals being pursued, Keane's theory does not use Holyoak's concept of deep structure. According to Keane, the set of attributes and associations relevant to the structure of the solution in both domains cannot be identified until the solution has been generated. Likewise, only at this point can the features not directly relevant to the solution (i.e. the surface structure) be identified. Thus, no a priori distinction between deep and surface features exists in Keane's theory because no such a priori distinction can exist in his theory.

Keane's Experimental Evidence

To test his theoretical claims, Keane (1985, 1987, 1988) manipulated problems like the Lightbulb problem and the General problem. Two research outcomes that Keane cites in support of his theory will be briefly presented here. The two theoretical claims that these support are: i) the claim that a deep structure representation of the problem described by Holyoak is not required to map a solution from one problem to another, ii) that solutions are generated in a piecemeal fashion whereby critical objects and functionally relevant attributes direct the mapping activity in the solution generation process.

Keane (1988, Experiment 4) attempted to examine Holyoak's claim that the process of generating a solution requires subjects to use a representation of the deep structure of the problem including its goals, constraints, and resources. He presented subjects with the Radiation problem, followed by a series of four solutions to other, unfamiliar problems. One of these was the solution to the analogous General problem in Table 3. The alternate solutions were composed of association patterns less similar to the Radiation problem, such as the solution to Keane's Wine Merchant problem, also presented in Table 3.

Keane (1985) found that many subjects were able to select and use the solution to the General problem to solve the Radiation problem. Since subjects were only exposed to the solution portion of the General problem, not the problem itself, they were not provided with the problem's deep structure. Keane concludes that subjects' recognition of the appropriateness of this solution in preference to the other three could not result from the use of an abstract representation of the deep structure as Holyoak proposes. Rather, the relevance of the solution to the Radiation problem must have been derived by identifying corresponding objects, and recognizing their corresponding roles from the information portrayed in the solution itself.

Keane (1988, Experiment 5) provides further evidence that the solution generation process occurs in a piecemeal fashion, and highlights the essential role of the functionally relevant attributes of critical objects in directing this process. To illustrate this, Keane presented subjects with a vehicle analogous to a target problem except for a mismatched attribute between the objects critical to the solutions of the two problems. To illustrate, consider the solution to the Businessman problem in Table 3. The overall structure among the objects in this problem is similar to that of the Radiation problem and the General problem; the solutions to all three involve several objects being divided and sent by multiple routes to a central location where they converge to produce a desired effect. However, the solution to the Businessman problem does not endow the pieces of mail with the attacking attribute prominent in both the rays in the Radiation problem and the soldiers in the General problem. Keane refers

Table 3

Solutions to the General, the Wine Merchant, and the Businessman problems

Solution to the General problem

The general, however, knew just what to do. He divided his army into several small groups and dispatched each group to the head of a different road. When all was ready he gave the signal and each group marched down a different road. Each group continued down its road to the fortress so that the entire army finally arrived together at the fortress, at the same time. The fortress fell and the king was forced into exile (Keane, 1988, p.121).

Solution to the Wine Merchant problem

The second merchant tried a different tactic. He poured the wine out of all but one of his barrels, and lashed then together to form a raft; then he loaded the one full barrel, a horse and himself on top. He set the raft adrift and floated down stream. In a few minutes the raft came to rest on the shore in front of the town where the rich man lived. The merchant disembarked, loaded the wine barrel on the horse, and led it to the rich man's house. He arrived just as the sun was setting, and collected the gold brick as a reward for his efforts (Keane, 1988, p.122).

Solution to the Businessman problem

The business man knew just what to do. He divided his mail into several small groups of parcels and sent these groups along a number of different routes, so that they arrived together at the post office, all at the same time, thus fulfilling his wish (Keane, 1988, p.123).

to this feature as a functionally relevant attribute. Keane gave one group of subjects this Businessman solution as the best match to the Radiation problem, of the three solutions presented. These subjects were marginally less successful at finding the solution to the Radiation problem than subjects who were given the General problem's solution as one of the three presented. However, roughly half of the subjects in this condition were able to identify this Businessman solution as the most applicable to the target problem. These subjects were simply unable to map the appropriate structure to achieve the solution itself. In contrast, few subjects presented with the General solution showed this successful recognition accompanied with failed mapping.

This finding, that a functionally relevant attribute mismatched between problems can result in a powerful disruption in the mapping of a solution, supports the view that the solution generation process occurs in a piecemeal fashion. In explaining this Keane (1985) refers to the concept of "growth from a focal proposition". In his words, "Focal proposition growth refers to the generation of solution propositions by an iterative process of testing propositions as conditions of current subgoals and main goals, and then amending subgoals on the basis of these tests" (p. 456). He believes that this growth may begin successfully because some focal proposition corresponds between the two problems, and grow successfully until a break in this correspondence occurs at a critical point. Keane further explains that if this occurs, the system may form partial solutions based on the satisfaction of some subgoals identified in the problem. In the Businessman problem condition this resulted in some of Keane's (1988) subjects proposing that the surgeon in the Radiation problem should send high intensity rays from many different directions. This solution addresses the subgoal of debilitating the tumour, but sacrificed the subgoal of preserving the healthy tissue. This sacrifice was probably caused by subjects' exposure to the Businessman problem where the successful solution used converging forces without regard for the medium they travelled through. Another example of a partial solution generated by compromising these same subgoals appears in Gick and Holyoak's (1980, Experiment 1) work where subjects suggest that the surgeon should make an incision to allow radiation to pass through the healthy tissue to the tumour.

Summary and conclusions

This review of theories of analogy problem solving has illustrated two important theoretical issues which will be addressed throughout this thesis; one regards *how* solutions are transferred from vehicle to target domains, while the second regards the questions of *what* is transferred in this process. Gentner has argued that this information is transferred en masse, via a holistic, skeletal structure of associations, whereas Holyoak and Keane have broken down this process into steps. Holyoak sees this process as one that unfolds gradually as associations making up the deep structure are initially matched between domains, and more detailed correspondences are subsequently established from these. Keane proposes an even more piecemeal process where detailed attributes and associations are transferred step by step under a continual monitoring process to ensure the solution progresses toward desired goals.

The second, highly related issue of what kind of information is transferred in this process also distinguishes these theories. Gentner proposes that the solution is transferred as a highly abstract association structure. Holyoak acknowledges the primary importance of associations, but also provides a place for object attributes in his view that this information takes the form of propositions organized around the problems' goals, constraints, etc. Keane proposes an even more analytic representation of this information by claiming that a single object, or even one of its attributes, can have a central role in the solution process.

In the discussion of the processing of four word analogies later in this thesis, both sides of each of these issues are accommodated to some degree. In the more immediate focus however, the remainder of this chapter continues to outline aspects of analogy problem solving that are amenable to the procedural view of cognitive processing I wish to develop here. Many of these aspects central to the procedural perspective appear in Keane's theory. For example, Keane emphasizes the *process* of analogical transfer, not the *structure* of the information transferred. Secondly, the pattern of activation used in this process is guided by the semantic detail learned from specific instances; it is not guided by general rules. Thirdly, the memory of these patterns of activation enable preceding processes to guide each subsequent process according to the direction taken in a previously learned instance. Finally, this high degree of guidance from previous instances renders this type of processing relatively effortless, since few decisions in the transfer process require explicit, conscious judgement.

The next section of this chapter elaborates on some more aspects of processing compatible with procedural views of cognition by reviewing some theoretical contributions to analogy problem solving from researchers of artificial intelligence. In the last section of this chapter a procedural view of processing is used to describe a short-cut through the componential model of cognitive processing that I propose for four word analogy problem solving.

Section 3.2:
Other Contributions Toward A Model For Analogy Problem Solving

Overview

This section describes procedural models of cognitive processing proposed by researchers of artificial intelligence in order to provide details about how analogical problem solving might occur. First Anderson's ACT theory is described to introduce two concepts central to his theory: the propositional fan and IF-THEN production rules. The works of Carbonell (1982, 1983a, b, 1986) and Burnstein (1983, 1986) are then briefly introduced to describe how they use procedural views to address particular problems inherent in the studies of analogy problem solving generally. These include the question of how the subject's cognitive system chooses a starting point, and how the system prevents future applications of the solution process from repeating past mistakes.

Anderson's ACT Theory

Anderson (1976, 1983) proposed a theory of semantic memory based on a network model where concepts are represented as nodes, and associations are represented as connections among these nodes. Propositions are units of this network made up of two concepts (the subject and predicate) and an association connecting them. Within this network a story, or any sequence of thoughts, is represented by a connected sequence of these propositions. Likewise, the memory of a story (or any piece of it) requires the re-activation of that proposition or sequence of propositions. Two theoretical constructs used by Anderson in ACT theory are outlined. The first is the propositional fan. This will be discussed as one of the factors affecting the likelihood that a proposition will be remembered. The second is Anderson's IF-THEN productions. These act as rules by which a proposition is re-activated from memory. Generally the circumstances that have preceded a proposition in the previous uses become the IF conditions that must be satisfied before the proposition can THEN be re-activated. When the IF condition of these rules consist of the activation of an earlier proposition, these IF-THEN rules link propositions and can form an activation pattern that represents a story or problem in memory.

Factors Affecting Proposition Strength

Anderson's (1976, 1983) theory is based on a network model, similar to Collins and Quillian's (1969) activation model in the way concepts are connected by association pathways between them. However, unlike Collins and

Quillian, Anderson assumes that propositions differ in their strength, and that this strength is enhanced by the frequency and recency of their use. Anderson's theory holds that commonly used propositions are more readily activated than rarely used ones. For example, the phrase *the army attacked the fortress* should be more readily retrieved than the phrase *the army converged on the fortress* because it is more often used in everyday language. Propositions that have not been activated recently will become less accessible through an automatic de-activating process that Anderson refers to as dampening.

The second factor determining the relative strength of a proposition is the number of other associations that connect with concepts that make up that proposition. Anderson refers to these alternative associations as the propositional fan for a particular concept or association. A large number of competing associations with a particular concept constitutes a larger sized fan, and results in a less powerful memory for each individual association within that fan. For example, the phrase *the army attacked* which appears in the sentence *the army attacked the fortress* also has associations with other objects that armies are known to attack, such as other armies, bridges, airports, demonstrators, etc. According to ACT theory, the propositions formed by these other objects (e.g. *the army attacked the protesters*, *the army attacked the airport*, etc.) decrease the accessibility of the proposition *the army attacked the fortress* because they compete with this proposition for re-activation.

Accordingly, the memory for a proposition should be enhanced by the use of very specific concepts or associations in that proposition, since more specific concepts should have a relatively narrow propositional fan. For example, a proposition using the relatively specific concept *rays* should be more readily recalled than one using the concept *weapon*, simply because *rays* probably has formed fewer propositions in the subjects memory to compete with the target proposition. *Weapon*, being a less specific word, should form a wider propositional fan. While this example illustrates the proposed effect of propositional fans on memory for *concepts*, similar effects hold for *associations* of different degrees of specificity. For example, the memory for the phrase *the tumor was singed with the rays* should be stronger than for the phrase *the tumor was attacked with the rays* because the specific phrase *was singed with* should have a narrower propositional fan than the phrase *was attacked with.*

IF-THEN Conditions As Memory Cues

Anderson's (1976, 1983) theory also describes how the memory of a proposition is strengthened by the re-occurrence of the conditions that lead to its initial encoding. Anderson describes the link between a proposition and its antecedent thoughts as *productions*. This link becomes manifest as IF-THEN, or condition-action pairs whereby IF particular conditions recur, THEN the proposition is reactivated. For example, IF the subject thinks of the General problem and tries to recall propositions relating to the concept *attack*, THEN the propositional fan for this concept will be stimulated and the strongest proposition within that fan will be activated.

These IF-THEN productions can be used to explain the recollection of sequences of propositions making up stories or problems because they may be embedded. That is, the memory for one proposition may become the IF condition for the act of remembering the next in a sequence or story. Anderson uses the term *production systems* to refer to productions linked in sequence to perform larger cognitive operations. Through these production systems, the memory of a story line can be recalled in successive steps where each production is tested in turn. If an early production in a system is successful, it activates a proposition strongly associated with another later in the story line. If this association is strong enough, this next proposition is also recalled, and so on, until the larger problem or story line is activated intact.

ACT Theory and Keane's Theory Compared

Anderson's propositional fan and IF-THEN production rules can both be applied to Keane's theory of analogy problem solving. In both cases I believe Anderson's description of these concepts provides greater understanding of similar processes in Keane's theory. The characteristics of Keane's work relevant to propositional fans and IF-THEN productions are, respectively, i) the use of specific objects' attributes and associations during the process of mapping a solution from one problem to another, and ii) the step-by-step process underlying the mapping of a problem's structure and the direction given to the association path by this process. This section outlines the application of these two concepts as a further step toward the presentation of the processing model proposed later in this chapter.

Anderson's IF-THEN productions capture some essential aspects of Keane's step-by-step orientation to transferring information during analogical problem solving. According to Keane, in the simplest case of mapping a vehicle to a target problem, the transfer of one association leads directly to the transfer of the next most related association in the vehicle domain, and this occurs in a progression that recapitulates the pattern of associations essential to the complete solution of the problem in the vehicle domain. This pattern of activation is directed by the associations in the vehicle domain, which were formed when the problem was originally solved. Likewise, in Anderson's description of the recall of a story, the completion of one production becomes the antecedent IF condition for the next production in the system. If successful, this system of reactivated productions continues until the complete story or problem is recalled. The direction for this pattern of activation is provided at each step in this sequence by the IF-THEN associations formed during the original encoding of the story.

Anderson proposes that the execution of these productions is automatic and greatly influenced by the recency and frequency of previous uses. In light of the similarity between Anderson's description of this construct as a characteristic of remembering, and the processes described by Keane, it seems reasonable to expect that these same characteristics of automaticity, recency and frequency should also apply in the case of analogical transfer.

A potentially parallel construct for Anderson's propositional fan can also be found in Keane's emphasis on the role of specific object attributes and associations during the mapping process. According to Keane, specific correspondences between objects in vehicle and target domains help subjects identify which objects in the vehicle domain are relevant to the solution and should be mapped. This benefit results because these specific corresponding attributes of these relevant objects serve to distinguish them from others in the vehicle domain that might also share some corresponding attributes with target objects and compete with them for recognition as objects relevant to the solution. For Anderson, specific concepts strengthen the memory of each proposition they form because their semantic detail results in the formation of smaller propositional fans. When the system attempts to recall a proposition involving a specific concept, that proposition is easily reactivated because relatively few other associations compete with it in the propositional fan.

Both Anderson's and Keane's theories are amenable to the procedural view of processing; both are process oriented, and both emphasize the role of instances in the development of these processes. Both propositional fan and IF-THEN production rules find similar counterparts in Keane's theory, and Anderson's characterization of these constructs as automatic, both in their formation and execution, can be accommodated easily by Keane's theory. Later in this thesis these constructs and their characteristics of automaticity are incorporated by the procedural model of cognitive processing described in my model for solving four word analogy problems.

The Contribution Of Artificial Intelligence Research Toward A Procedural Theory Of Analogical Thinking

The following discussion of artificial intelligence research on analogical problem solving is by no means thorough. The work of Carbonell and Burnstein are presented because they have addressed specific questions relevant to the processing of analogy generally, and because their contributions to these questions help to provide further details about the procedural view of cognitive processing I wish to promote.

Carbonell's Work

Carbonell's (1982,1983a,b,1986) Derivational Analogy Theory is one of the most widely documented theories of analogical thinking in the field of artificial intelligence. Carbonell elaborates several aspects of theory compatible with a procedural view of analogical problem solving. I will briefly present his ideas about three issues: i) how an appropriate vehicle is chosen, ii) how discrepancies between vehicle and target problems are overcome, and iii) how the system is cued to find the next association in a sequence leading toward the chosen goal.

The question of how the system selects a suitable vehicle from those available in memory is addressed by Carbonell (1983a) through a process called reminding. The reminding process compares several potential vehicle problems to the target problem for the purpose of determining which is most similar to the target. This similarity judgement is formed by a series of comparisons between representations of vehicle and the target problems. These representations are of a form similar to that described by Holyoak as a problem's deep structure. The ultimate goal of these comparisons between deep structures is to derive an index indicating how successful the solution strategy used in each previous problem would be in achieving the goals of the new target problem, given the constraints that exist there. The series of comparisons used to form this index are: i) a comparison of the deep structure of the target problem before the goals are met with the initial deep structure of previously solved problems, ii) a comparison of the structural changes that would be required for the goals to be met in the target problem with those changes made in previous problems, and iii) a comparison of the constraints that prevent these changes in the new problem with the constraints encountered in previous problems. Thus, through this reminding construct Carbonell has offered a type of screening device for choosing the best vehicle with which to attempt analogical mapping. This device is essentially a preview of each potential vehicle problem performed in a highly structured, step-like manner.

Carbonell (1982,1983a) also proposes a method for reducing discrepancies between the target problem and the chosen vehicle, by transforming the representation of the former. After reminding has been performed, transformation operators (T-operators) are applied to the objects of the target problem that are initially discrepant from those in the chosen vehicle. These T-operators function within the constraints of the target problem to transform its objects to states more similar to those of the objects in the vehicle problem. In the Radiation problem, for example, if only one laser machine is available and it cannot be moved, a T-operator might transform the representation of the human body into an object which can be rotated in front of the laser. This would allow the function of the rays to become more similar to the converging army in the General problem by allowing these rays to converge on a single point within the body from many angles.

Thus, T-operators are procedures for overcoming discrepancies between the structures of target and vehicle problems. They are primarily formed in the course of solving problems where similar discrepancies have been encountered and overcome. In this way a subject's cognitive system gradually acquires a collection of T-operators through problem solving experiences. Each discrepancy between a new target and a vehicle problem is essentially treated as a sub-problem addressed by searching for an appropriate solution (T-operator) to transform the objects involved.

Whereas T-operators can be described as general strategies stored in long-term memory and kept ready to be applied to new problems when familiar structure discrepancies must be overcome, Carbonell (1986) also describes a set of information that is stored with the representation of each particular vehicle problem and is used only when that problem is applied as a vehicle. This information constitutes a record of the association paths activated in the execution of the solution to that problem including, but not confined to, those that were found to be unsuccessful. This information potentially serves two functions. First, if association paths that failed to lead to the solution in a vehicle problem are recalled, the old failed path might be used to find the solution to the new target problem in cases where this problem differs from the vehicle in relevant ways. That is, the reasons for the failure of these paths might be invalidated by the details present in the new, target problem. Thus, one use for this record is to have information available about previous unsuccessful solution attempts and the reasons for their failure, so that they might be used constructively in the solution of future problems.

A second potential use for this record is to cue the system about the order of associations that occurred when the original solution was achieved. Carbonell (1986) explains that when a solution is transferred, the association paths attempted during the solution of a new problem occur in the sequence originally performed. That is, the sequence of associations activated during the attempted solution of the target problem is guided by the order in which these associations originally occurred in the vehicle problem. While this procedure ensures that the associations from the vehicle's record which were irrelevant to the solution will be reactivated in the target problem, the record also identifies these as unsuccessful associations and ensures that the subject progresses beyond them toward more successful association routes.

Keane (1988) believes this process of reconstructing and evaluating association paths from old problems is similar to case-based reasoning strategies used by practitioners of medicine and law. By this view each step of the thinking that occurred for case X is recalled so that those steps relevant to case Y will be recognized in the same order that they were relevant to case X. As well, the mere repetition of these steps in an orderly fashion might ensure that all the relevant information available will be considered. Furthermore, this might ensure that the irrelevant associations and mistaken strategies made in case X, will be remembered as such, and are thereby given minimal attention in case Y.

Burnstein's Work

Burnstein's (1983, 1986) work addresses a question raised by both the theories of Holyoak and Gentner: How does the processing system know which attributes of the objects in the vehicle should be mapped once the vehicle problem has been chosen? For example, in an analogy between the structure of the solar system and the structure of an atom, the **sun** is mapped to the **nucleus**. But how do we come to focus on the sun's density rather than its colour or heat? In Holyoak's work this is the problem of how subjects are able to determine the deep structure of a target problem before they know its solution.

Burstein (1983, 1986) explains that the first features in a vehicle object to be mapped to the target are those features causally related to the nature of the object as it is perceived in the context of the vehicle domain. These causally relevant attributes are like Keane's functionally relevant attributes, except that Burnstein focuses on the attributes that define the object (i.e. provide meaning for the object in the context provided). For example, in the context of the structure of the solar system, mass is more defining of the sun than its colour or heat. That is, in the subject's previously learned causal model of the sun's role among other planetary bodies, its mass is identified as a defining attribute. As a result, this feature is transferred first. To provide a contrasting example, if the sun is presented in the context of the day's weather system, its heat or position in the sky is a more defining feature, and will be more readily transferred than either its mass or colour.

Burnstein explains that following the initial transfer of this defining attribute, other attributes are mapped in turn, while the cognitive system monitors their importance to the meaning of the object. So, in the case of the solar system example, features like colour and heat may be transferred in this later processing phase, but the monitoring process will halt the transfer if these attributes are not recognized by its previously learned causal model of the solar system.

What is Burnstein's contribution to theory? His idea of definingness provides the mapping process with a rule for priorizing which of an objects' attributes are to be mapped. This appears to contrast with Keane's proposal that attributes functionally related to the critical objects are mapped first. However, for the purpose of choosing a starting point for mapping, this distinction between the theorists' emphasis on structure or function, respectively, may be more apparent than real; for objects directly relevant to the goals of the problem, their function may also define them in the context of that problem. As a result, Burnstein's contribution may be more unique as a general rule for mapping attributes of the other objects not as critical to the solution, later in the mapping process.

Section 3.3: Processing Models For Four Word Analogies

This section outlines two models for processing four word analogies. The first, Sternberg's model, presents many processing characteristics that guided my work and formed the basis of my processing model. After Sternberg's componential model is presented, my modified version is described in detail. This model is used throughout the remainder of this thesis to account for the processing of my four-word analogies. As each component in this model is presented, its relevance to the processing of the stimuli used in this thesis is discussed. The section ends with a statement about how this componential model relates to the procedural view of processing outlined in the previous section.

Sternberg's Model

Sternberg (1977) proposed a model[1] for four-word analogy problem solving which is the most well documented in the literature to date. The five components described in his model form the basis of the model I propose, and for this reason are each outlined here.

The five basic components of Sternberg's model are performed by subjects in sequence, where each component increments the time required to solve an analogy. The first component is called identification. It includes the activities of reading the words of the analogy, and of encoding their meaning. Encoding is assumed to involve translating the words that make up the analogy into a list of attributes that "experience has indicated are useful in relating one concept to other concepts" (Sternberg, 1977, p. 356). The encoding process also involves choosing, for example, which interpretation of a homograph to encode, based on the context in which it appears. To illustrate, in the analogy **hand : palm** as **foot : sole**, the word **palm** is read and encoded as a part of a hand, not as a type of tree. The encoded attributes of **palm** might include its characteristic smoothness, its hairlessness, and the fact that it is a body part.

The second component is called inference and refers to the process of deriving the nature of the association or associations that exists between the first pair of words in the analogy. According to Sternberg, this occurs by matching the attributes encoded for the first two words, sequentially, until features are found in each word that relate to one another. So, for the analogy **hand : palm** as **foot : sole**, the attribute of **hand** as a body part is chosen rather than its quality as a warm surface, or its ability to change shape. This attribute is matched to the corresponding attribute in **palm**. Sternberg (1977) believes this process occurs for all attributes of the two words that were initially encoded. However, attributes not encoded at the first component will not be considered during this search for matching attributes with **palm**. So for example, obscure attributes of **hand** such as its composition from 19 bones, will not be processed.

In the third component, called mapping, the third word is encoded and its attributes are compared to those of the initial word from the first pair. In Sternberg's model this process terminates when one of the attributes held in common between the first and third words is also relevant to the association between the first pair of words. When this attribute is found and mapped, then the next stage, application, may begin. In the above example, the fact that both **hand** and **foot** are body parts may be the attribute of **foot** that terminates this process and becomes the basis for further processing in the application component.

The application component uses the association discovered between the first two words of the analogy and applies it to the third word, in order to determine which answer alternative best completes the analogy. For the stimuli used by Sternberg, each answer alternative presented in a multiple choice problem is considered as a solution. When one of these is found to contain an attribute that matches the analogy-relevant attribute from the third word, it is used to construct an association that matches that of the first word pair, and the associated word becomes recognized as the solution.

The fifth component is the execution of the response. This component accounts for the time required to respond manually to the chosen alternative.

Sternberg also proposes an optional component, called justification, used by subjects when they are not certain about the best answer alternative. In this component subjects weigh the appropriateness of the provided response alternatives to justify their chosen response. In the modified model I propose, this component involves justifying a choice from among externally provided alternatives, and is called *external justification.*

A Modified Model

Sternberg's model serves as a useful starting point for the construction of my model since he too studied the response latencies of subjects solving four item analogy problems. (Most of Sternberg's experiments did not use word analogies.) However, several modifications to this model were required in order to accommodate the differences between the stimuli of the two research projects. The main stimulus differences that necessitated these alterations of Sternberg's model were i) the greater degree of difficulty of my problems resulting from the generally more complex relationship between word pairs, and between the two associations in my problems, and ii) my use of both a recognition paradigm (similar to Sternberg's multiple choice method) and a recall paradigm to study subjects' reactions to these problems.

Bases of Differences Between the Models

The greater difficulty of my stimuli compared to Sternberg's was necessitated by my goals. Within the problems used in my work, the similarity between two associations were often based on several characteristics. This was because my work was motivated by an interest in the relative processing demands of word analogies defined by different association types which may differ from each other according to several features or dimensions. In contrast, Sternberg (1977) used analogies made up of simpler associations because he was motivated by an interest in testing processing models. To be more specific, Sternberg measured the degree of similarity (number of features in common between words) within an analogy, and used this measure of analogy difficulty as his single independent variable. To ensure this simplicity he performed most tests of his model using nonverbal analogies constructed from geometric designs and human cartoon figures, where the number of features discrepant between the two items forming an association (eg. height, colour and sex of cartoon figure) were carefully controlled.

This difference between Sternberg's stimuli and mine led me to change several parts of Sternberg's processing model. First, because there were so many potential features to process in my stimuli it was expected that an exhaustive consideration of all possible features in the inference component would be virtually impossible. Likewise, different assumptions about how the attributes of the first word are mapped to the third word were also necessary in order to model the transfer of these relatively complex associations. In my model the mapping process is assumed to continue after the initial point of similarity is found because subjects processing my word analogies cannot be confident that the initial feature they map is the most critical to the association corresponding between the two word pairs.

The second source of stimulus differences necessitating modifications to Sternberg's model resulted from the use of two paradigms in my work. Both of these paradigms were substantially different from Sternberg's. Sternberg presented subjects with multiple choice problems where only two alternatives were to be chosen from. I believe this led his subjects to process the entire problem in an answer-driven manner, where they viewed the answer alternatives as part of the problem to be processed. In contrast, my paradigms did not constrain the answer alternatives to this degree. In my recognition paradigm subjects were presented four answer alternatives, and in the recall paradigm no answer choices were provided. These methods encourage subjects to generate answers internally, rather than to simply compare the appropriateness of the answer alternatives provided. This design modification also led to some additional changes in Sternberg's model. First, a greater processing demand is expected of the application component in my model because subjects responding to my analogy problems are expected to generate several potential answers for consideration later in the processing system. More difficult problems are expected to produce more answer alternatives and less certainty about each one. For this reason the application component is expected to account for a great degree of the latency variability between analogy problems of different levels of difficulty. A second consequence of generating several potential answers at the application component is that a subsequent component must be added where these alternatives can be compared to determine their relative suitability as an answer. This addition is referred to as the internal justification component of my model.

Critical Components of the Modified Model

This section will first outline the three components of my model that are critical in accounting for the processing of the stimuli used in my work. These are the inference, mapping and application components. The other two components described by Sternberg (encoding and execution of response) are expected to require the same amount of processing regardless of the association type appearing in the problem. No modifications of these are made in my model, and little discussion is made of them here. Following this initial outline, the distinction between internal and external justification components is made.

Inference. In Sternberg's inference component all features activated at the encoding component are matched exhaustively before mapping is attempted. However, Sternberg uses geometric figures and cartoon human figures composed of a relatively small number of readily identifiable attributes. These simple stimuli enable subjects to compare all attributes of the items within an analogy. In contrast, my stimuli use words which are comprised of such a rich set of semantic attributes that it is virtually impossible for the subject to consider these attributes exhaustively.

Thus, I believe the comparison of attributes in the first two words proceeds sequentially until a subject is able to infer an association between them. I believe this discovery of the association takes a variable amount of time depending on the type of association present. To account for this I propose a type of trial and error strategy for recognizing different association types, where if the most readily inferred association types are not found in a word pair, the identification of more difficult association types is attempted. This process is self-terminating in the sense that once an association is found, no others are sought out. However, since the inference of different types of associations necessarily requires the activation of different types of attributes in the words involved, it seems necessary to postulate that the activation of these attributes should become more and more exhaustive as progressively more difficult association types are sought out. Further, it seems likely that for very difficult association types, the set of initially encoded attributes about these word would become exhausted before an association is discovered. This might require the subject to spend some conscious effort to return to processing the words involved and encode these words with additional attributes. This process should occur, for example, for homographs which are initially misinterpreted, and as a result lead to an initial failure at the inference component.

I have no firm hypothesis concerning the basis of the hierarchy of difficulty for association types, and none will be tested in this thesis. One possibility however, is that semantic relations which are first learned developmentally, or are most often practiced in everyday thinking might constitute the most readily inferred types. Regardless, I expect this process of seeking out a succession of association types between the first pair of words ordinarily occurs automatically (i.e. without conscious direction), and in a consistent sequence for all analogy problems. These processing characteristics should result in each association type eliciting a characteristic solution latency for analogy problems of that type. The demonstration of this is one of the central goals of this thesis.

One characteristic of association types that I do present an explicit hypothesis about is inclusiveness. As is elaborated in Chapter Five, my inclusiveness hypothesis states that since noninclusive association types require an additional inferential step (relative to inclusive types), they are generally more difficult, and should elicit correspondingly longer solution latencies. I propose that this inference component is one point in the processing model where this additional processing time for noninclusive types is consumed.

Mapping. The second critical component taken from Sternberg's model is mapping. Sternberg (1977) assumes that mapping discontinues after an initial attribute is matched between the first and third words. This may occur for Sternberg's simple geometric and cartoon stimuli since his subjects might appropriately assume that when an attribute match is discovered between the first and third words, this attribute is enough to cue the entire association to be applied to the second pair in the analogy. My model assumes that the attributes of the first word which were activated in the inference component will be sought out in the third word, and that this will occur according to the same sequence that these attributes were initially found in the first word. In my model, the mapping of more than one attribute is attempted because the associations between words in my analogy problems consists of a sequence of characteristics which are based on a sequence of corresponding attributes in each word. For example, in the analogy **hand : palm** as **foot : sole**, the similarity between **hand** and **foot** will not be mapped according to a single attribute regarding body part. Rather, the additional attribute of these words corresponding to other characteristics of the association between **hand** and **palm** will also be mapped. These include characteristics pertaining to their locations on the human body, attributes pertaining to their construction, their shape, etc.

Furthermore, the degree of success in mapping this entire set of attributes to the third word was expected to affect processing at the subsequent application component. As will be elaborated below, a greater degree of match will allow mapping of a more specific association and, according to the characteristics of Anderson's propositional fan this should result in faster generation of a solution at the application component. This expectation influenced the design of my stimuli.

In light of the hypothesis that similar concepts in the first and third word positions would enhance the mapping of details between them and thereby create a processing advantage for these problems, it was considered necessary to control this type of similarity between first and third words across analogy problems. To illustrate this potential difficulty, consider two super/subordinate analogies, the first with similar concepts in the first and third word positions, **fruit : apple** as **vegetable : corn**, and the second using less similar concepts in these positions, **fruit : apple** as **game : monopoly**. According to the above argument the first example should result in a more complete mapping of attributes, and a more quickly generated solution. Since the critical independent variable in most of my research was the association type presented in each analogy, and since I intended to measure the effect of this variable by distinguishing different solution latencies between types, the potential influence of this kind of similarity on latencies across analogy problems was controlled by using word pairs drawn from taxonomicly similar subject areas in every problem. That is, my stimuli were designed like the first example presented above.

Application. In general application refers to the use of the association inferred in the first word pair, applied to the third word, in order to generate a fourth, solution word with this same association. The role of the application component in my model differs markedly from its role in Sternberg's model. Whereas Sternberg views application as a process where the viability of each provided answer alternative is tested in turn, I believe that for my stimuli the application component generates potential solutions from the information contained in the words of the analogy stem. That is, I believe this application process takes place before the subject proceeds to view the answer alternatives provided.

The time required to perform this process will depend on how many attributes have been mapped from the first word pair. If many have been mapped, much information about the association is available and the search for a solution word to replicate this association with the third word will be correspondingly fast. For example, in the analogy **hand : palm** as **foot : sole**, the pair **hand : palm** contains detailed information that can be applied to the third word **foot**. In this case, the solution word is the central part of the contact surface of the whole object to which it belongs. This information should lead quickly to the generation of **sole** as a solution word. In contrast, for cases where the analogy is not specific in this way fewer attributes will be successfully mapped, and the application component will generate several candidate solution words, and in a more time consuming process. For example, in the analogy **boat : mast** as **car : bumper**, the attributes of **boat** making up the first association do not also exist in **car**. That is, cars do not have tall poles extending from their center for the purpose of propulsion. Accordingly, the specific association between **boat** and **mast** cannot be applied to car. As a result of this mismatch among attributes, several words will be generated in an attempt to solve the problem using a more general (nonspecific) association.

This hypothesized influence of mapping success on the application component is predicted by the processing principles of Anderson's propositional fan. For specific analogies, specific associations are transferred from vehicle to target. According to Anderson, the number of concepts associated, to a specific association through their previous use is necessarily small. Therefore, the number of concepts that can be generated as solution words is small, and processing at this application component is correspondingly fast. More general associations have larger propositional fans and so require more time to generate a larger number of associated concepts.

Internal and external justification. Application processes that generate large sets of potential solution words also create a need for an additional processing component to choose among these alternatives. I propose an additional justification component. Because the function of this component is to choose among *internally generated solution alternatives*, I refer to it as *internal justification*. This is markedly different from the *external justification* introduced in Sternberg's model, since Sternberg's justification component is a process where subjects compare *the given multiple-choice alternatives* in order to justify their choice of the best answer.

My stimuli require internal justification for both recall and recognition paradigms. In the recall paradigm, no answer alternatives are presented, so if two or more alternatives are generated during application, a choice cannot be made among them by consulting externally provided alternatives. In the recognition paradigm, I believe internal justification occurs before the multiple choice alternatives are inspected. I believe this occurs for two reasons. First, the very process of understanding the problem and mapping common attributes from the first to the third word should automatically result in the generation of candidate solutions in the application component. If this is the case internally generated alternatives should receive processing before externally provided ones simply because they are presented to the cognitive system first. Secondly, if subjects generate these multiple alternatives automatically at the application component, they are unlikely to intentionally increase the processing demands of the task by seeking out further alternatives among the multiple choice answers. The processing demands of the task they are performing should discourage them from doing this until they have first considered the internally generated alternatives, and have developed the need to find external guidance to help to decide among them.

For some very difficult analogy problems, however, the need for this external guidance may arise and subjects may abandon the internal justification process because external justification seems more efficient. To illustrate, consider the analogy **car : wheels** as **boat : _____** . A subject might initially make any or all of the following inferences about solutions: i) that **hull** may be the answer because it is the contact surface of the vehicle, ii) that **rudder** may be the answer because it is the part of the vehicle used for steering, or iii) that **bumper** is the answer because it is an inflatable part of a boat. In both paradigms the application process will lead to an internal justification process to decide among these alternatives. In the recognition paradigm this process might be truncated if the subject realizes that the association required is a general one, infers that the solution word could be any boat part, and abandons the internal justification process to inspect the answer choices provided.

Although these proposals about the roles played by the two justification components will not be directly tested by explicit hypotheses, they are described here because they elaborate the procedural view I have used to describe my processing model. That is, they describe the processes of how detailed information about specific associations becomes transferred through the automatic replication of their cognitive procedures in the context of the third word in an analogy problem. More importantly, these two justification components are described here because they will be used later in this thesis to account for the interactions of solution latencies between the two paradigms used in the experiments reported below.

The Procedural Nature of Processing in Inference, Mapping and Application Components

In this thesis I have found it useful to describe the process of forming an association as a detailed cognitive procedure which, once used in the first instance, is readily replicated in other contexts. Largely for this reason, the preceding discussion has described procedural aspects of existing models of analogical problem solving, and has incorporated many of them in the description of my processing model.

This section is intended to summarize the relevance of this procedural view of cognition to the processing of my four word analogy problems in my componential model. It also previews the formal hypotheses resulting from my processing model, which will be presented in further detail as they are tested in the experiments reported later in this thesis.

Inference. Different association types can be regarded as different cognitive procedures whereby each analogy using the same type of association shares some essential processing steps in common. For example, in the analogy **hand : palm** as **foot : sole** the association between **hand** and **palm** is defined by its whole-part characteristic. This characteristic results in a particular sequence of cognitions to occur as the subject discovers this association characteristic in the first word pair. This sequence of cognitions may include rejected attempts to find other more readily generated types of associations, such as language based associations (as in **hand-stand** or **hand-bag**), or action oriented types (as in **hand-clap** or **hand-shake**). In the case of whole-part associations this process of discovering the defining whole-part characteristic will also include an analysis of the concept **hand** as an object composed of parts, and a recognition of **palm** as one of these parts. A similar set of cognitive steps will comprise the association procedure for any analogy problem based on this whole-part association type. Conversely, a different set of cognitive steps will form the cognitive procedure for analogy problems of different association types.

The postulation of such a common association procedure for associations of the same type is the basis for a general hypothesis motivating this thesis: that analogy problems of different association types will exhibit characteristically different solution latencies as a product of their differing cognitive procedures. To illustrate, consider the object-action association type. In contrast to the whole-part associations described above, the discovery of an object-action association might include fewer time-consuming, distracting attempts to form other, more readily accessible types of association, simply because this association type is itself highly accessible. Although no firm hypothesis will be tested regarding the cause of this general accessibility, an hypothesis regarding the functional/structural dimension is proposed, and serves to test a speculative explanation. This explanation suggests that the readiness of the inference component to process different association types may depend on the relative developmental order of the cognitive abilities underlying these association types, and/or the relative frequency of their use in everyday thinking.

This procedure of cognitive steps comprising the defining characteristic of an association type also accounts for the inclusiveness hypothesis tested in this thesis. Consider for example, the part-part characteristic of the association in the analogy **sock : glove** as **foot : hand**. The cognitive procedure required to discover this association characteristic must include the additional inferential steps to form a noninclusive association, and so should be a more time consuming procedure. This should ultimately result in generally longer solution latencies for analogies of this association type.

Mapping. It is assumed that the mapping component is predisposed to find attributes in the third word which are closely matched to the association-relevant attributes of the first word. This is consistent with procedural principles which hold that these specific attributes in the third word should become activated in the same sequence in which they were instantiated when the first association of the analogy problem was formed. Such a process could make use of a record, like Carbonell's record for analogy solution transfer, where all the attributes initially activated in the first word are referenced (including those that were not found to be relevant), and used to guide the pattern of attribute activation in the third word. Such a record would help the system maintain its efficiency by avoiding mistakes or distractions when mapping these attributes to the third word.

The ultimate significance of this process to problem solving is that if a specific match is found, it cues the system to use a specific association during application. Since this specific association employs a relatively narrow propositional fan during the application component, it ultimately serves to reduce the solution latencies for highly specific analogies.

Application. In this component the processing advantage for specific analogies is accounted for by the processing characteristics of Anderson's propositional fan. Specificly matched words associate with more specific associations, and these in turn lead to smaller propositional fans which generate specific solutions with great efficiency. (For a more detailed account of how this propositional fan might operate according to procedural processing characteristics such as IF-THEN production rules, see Appendix C.) This savings in processing time is also further accounted for at the justification component since specific analogies that produce few candidate solution words also require little processing time to justify a response among them. Thus, the processing savings hypothesized for analogies with specificly matched associations (i.e. the specificity hypothesis) can be explained as a procedural short-cut through mapping, application and justification components of my processing model. The processing of specific analogies is procedural in nature in that this short-cut results from the replication of a specific, previously processed instances in an automatic, relatively effortless manner.

CHAPTER FOUR: PILOT WORK

Overview

This chapter reports on initial attempts to study the processing demands of different types of analogies. A series of three pilot experiments was conducted. This chapter describes the methods used for this work and outlines the main findings. The outcomes of these experiments provided direction for the choice of analogy types used in the stimuli of the main experiments, and lead to some methodological modifications in these experiments. The discussion section of this chapter outlines these contributions of the pilot work to the later experiments.

Goals

The absence of an extensive literature or established methods for studying four word analogy problems necessitated a series of pilot studies. These experiments addressed two general goals. One was to develop and fine-tune a general method for investigating the cognitive processes involved in solving four word analogies. The second was to discover various analogy types that might reveal the nature of the cognitive procedures used to solve analogy problems.

Two paradigms were used. The recognition paradigm tested how quickly subjects could solve analogy problems when multiple choice alternatives were provided as solutions. The free recall paradigm tested subjects' ability to solve analogies when they had to produce the solution word. Subjects' solution responses to analogies of different types were compared between paradigms in order to observe how the different task demands of these paradigms would affect subjects' solution latencies across these analogy types. It was expected that these paradigms would provide different but convergent data on the cognitive processes subjects use to solve different analogy problems.

The selection of analogy types was guided by three general factors. First the early word association literature had consistently suggested two distinctions among association types. Cattell and Bryant's (1889) logical/objective distinction lead me to include logical, taxonomic types such as the super/subordinate type, and to include objective, analytic types such as the whole-part type. These authors, and others, also distinguished associations which related pairs of concepts at different levels of analysis (such as whole-part and super/subordinate types) from those that relate pairs of concepts at the same level of analysis, as in same class and part-part associations. This is the distinction between inclusive and noninclusive types, respectively.

A second factor directing the selection of analogy types for the pilot tests was the desire to test specific and nonspecific analogy problems with my paradigms. This necessitated the inclusion of two groups each of part-part and whole-part analogies. Analogy problems of the specific part-part and specific whole-part types were composed of pairs of inter-word associations which were very similar to each other. For example, in the specific whole-part analogy **hand : palm** as **foot : sole**, the spatial/functional relationship between **hand** and **palm** is very similar to that between **foot** and **sole**. In the nonspecific version of these analogy types, the pairs of associations used in each were not as closely matched, as in the nonspecific whole-part analogy **boat : mast** as **car : bumper**.

A third goal served by the selection of analogy types in the pilot work was to observe the processing differences for analogy problems using associations representing different levels of cognitive sophistication. For example, the object-action association type was thought to be a cognitively simple one since the relationship between objects and their actions appears in the cognitive repertoire of children early in development. On the other extreme, highly analytic and symbolic analogies, such as those based on part-part and sign/symbol associations, respectively, were also included to represent more cognitively sophisticated association types.

General Method

The general method described here was used for many of the experiments in this thesis and is therefore described in detail. Deviations from this method are noted as each experiment is described in subsequent chapters.

Subjects

All subjects were between the ages of 18 and 30, and over 90% were younger than 23 years. Fifteen male and fifteen female subjects were used for each of these studies. All were volunteers from the U.B.C. Psychology Department subject pool and participated for course credit.

Stimuli

The stimuli were four-word problems that presented the first three words of an analogy, such as **fish : school** as **goose :** _____ , and required subjects to complete the problem with a word such as **gaggle**. These problems were presented in a different format for the recall and recognition paradigms. In the recognition paradigm, these problems were displayed on a computer monitor in the following form:

FISH : SCHOOL
GOOSE :

1)MINNOW 2)HAT 3)GAGGLE 4)BAND

Subjects were asked to select the correct solution word from the alternatives provided. In free recall format only the three word stem (in the above example, FISH, SCHOOL and GOOSE) was presented without the answer alternatives, and subjects were asked to say the answer aloud. Analogies always took the form of an A : B as C : D ordering where the association between A and B was similar to the association between C and D.

Five examples of each of sixteen types of analogy problems were constructed. Table 4 lists the types and an example of each; a complete list of all eighty problems is presented in Appendix D. The recall and the recognition formats used the same set of eighty problems. For each analogy in the recognition format, the three incorrect answer alternatives provided were i) a word that had a familiar association with the first word of the analogy (FISH -- MINNOW in the example displayed above), ii) a common homograph which was not associated with any of the stimulus words by either of its interpretations (eg. BAND), and iii) a randomly chosen word that was not closely associated with any word in the problem (eg. HAT). In all problems the analogy word stem and the answer alternatives consisted of common words intended to tap a grade eight level of vocabulary skills.

Procedure

Each subject was seated alone in a small experimental room. A single page was used to introduce the experiment and to outline its general goals (see Appendix E). Subjects were told they would see eighty analogy problems, and that they should solve these problems as accurately and quickly as possible. Subjects were then given a practice test using the same paradigm they were tested with in the subsequent experiment. The practice test consisted of fifteen stimuli, made up of analogy problems from each of fifteen analogy types used in the study. Every subject completed at least twelve of the fifteen problems correctly, and was asked to review those that were answered incorrectly.

Table 4

List of Analogy Types Used in Pilot Experiments
and an Example of Each Type

Abbreviation	Name of Type	Example
CHAR	Object-Characteristic	lead : heavy :: cork : bouyant
OB/PUR	Object-Purpose	sandwich : eat :: shoes : wear
OB/ACT	Object-Action	hammer : pound :: saw : cut
SPRE1	Specific relation (block 1)	mask : face :: helmet : head
S/W-P	Specific Whole-Part	foot : sole :: hand : palm
SPRE2	Specific relation (block 2)	menu : meal :: map : trip
SUP/SUB	Super/Subordinate	animal : dog :: insect : beetle
SYN	Synonyms	cry : weep :: yell : shout
ANT	Antonyms	brief : long :: dark : light
W/P	Whole-Part	bicycle : brakes :: ship : mast
SA/CLA	Same class	daisy : tulip :: pine : maple
SP/P-P	Specific Part-Part	hand : elbow :: foot : knee
SIGN/SYM	Sign/Symbol	love : kiss :: fatigue : yawn
CAU/EF	Cause-Effect	food : growth :: work : wealth
SEQ	Sequence	dime : penny :: decade : year
P/P	Part-Part	wing : beak :: paw : tail

Subjects were not told about the different analogy types. Instead, feedback took the form of the experimenter suggesting answers to the problems and leaving subjects to infer how these solution words were associated in each problem.

Immediately following the practice test subjects were given the eighty item test. The problems were presented in green, phosphorescent, capital letters against a black background on an Apple IIe monitor. Subjects were instructed to press the appropriately labelled button on a keypad to indicate their response (i.e. 1, 2, 3, or 4). The problems remained on the screen until one of the response keys was pressed. The duration of time from the onset of the stimulus to the subject's response was then recorded. Following a four second delay, a new problem appeared on the screen to begin the next trial. No feedback was given to the subject at any time during this test. The order of presentation was completely randomized across the eighty analogy problems, and a different random sequence was used for each subject.

The second part of the pilot work (Pilot Experiment 2) used a free recall method that required subjects to generate and say aloud their solutions to each problem. The general procedure was the same as that for the recognition paradigm, with the following exceptions. Stimuli consisted of only the three word stems from the analogy problems used in the recognition paradigm. Subjects responded to each problem verbally by speaking into a hand-held microphone which recorded the latency of the spoken response via a voice activated timer. A second microphone mounted on the computer case recorded these spoken responses on a walkman cassette tape recorder.

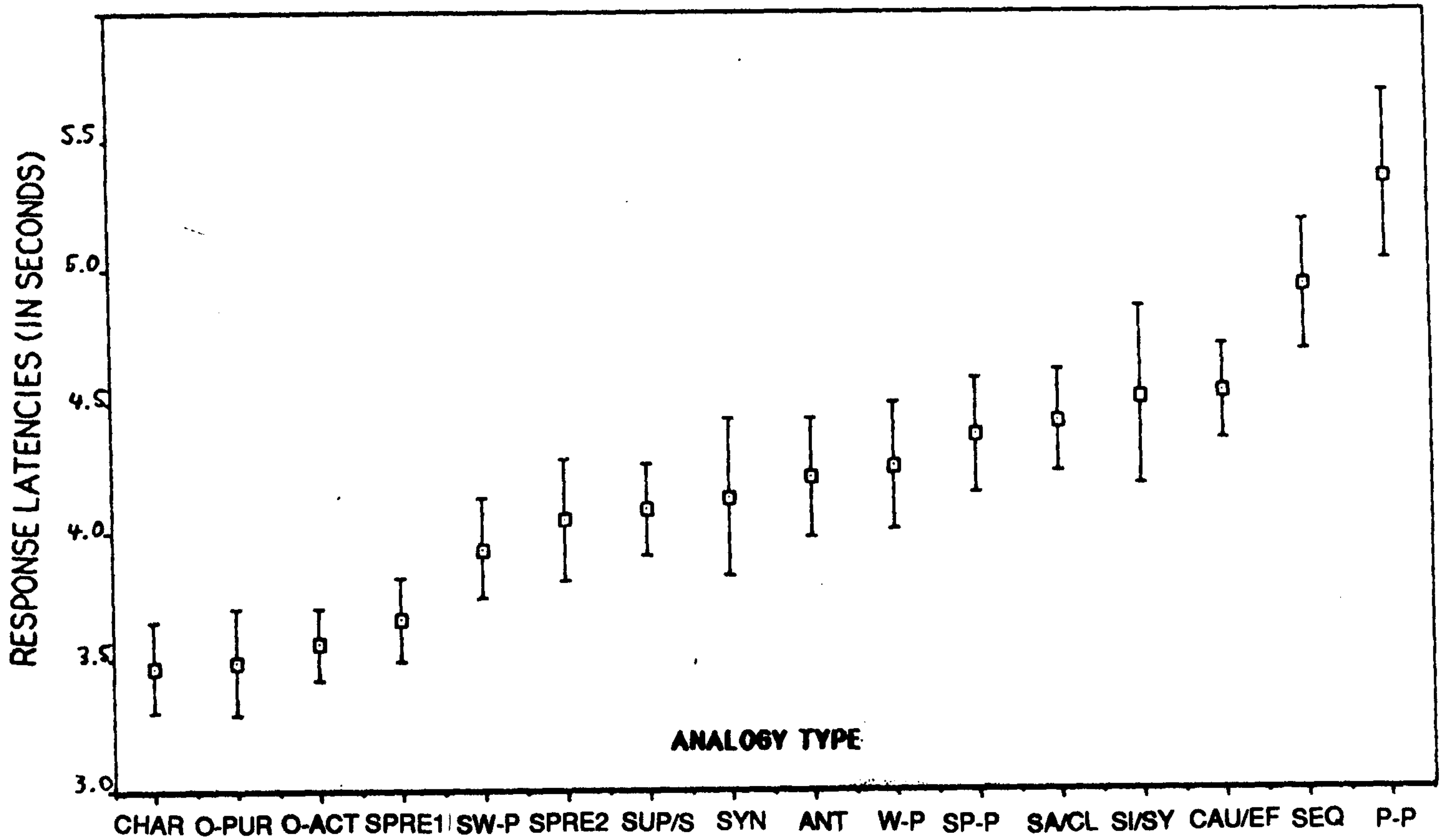
The general procedure for the recognition paradigm was modified for a third study (Pilot Experiment 3) that attempted to prime analogy solutions. In this procedure, the five analogies of each type were presented in a block of consecutive trials. Each block of trials was preceded by a notice informing the subject of the beginning of a new block; they were told "You are now starting a new block of analogies using a different type of pattern". Both the order of the blocks and the order of the problems in each block were randomized across subjects. The general instructions were also modified to inform subjects that the stimuli within a block would be similar to each other, and that this similarity was based on the nature of the association between the words that make up each problem. Subjects were instructed that this similarity might assist them in finding solutions to the problems, but were not told which association types to expect. This design allowed subjects to learn the nature of the analogy type in the first few problems of each block, and to used this information to prime their responses to the subsequent problems in the block. It was expected that blocks consisting of problem using associations that subjects found to be psychologically similar would show a priming effect (i.e. the savings in solution time in this condition relative to the random condition).

Results

Pilot Experiment 1: Random Presentation of Analogies in the Recognition Paradigm

The two dependent variables recorded in this experiment were the accuracy and latency of responses to each analogy problem. The analysis of latencies used subjects' median response time on the five problems of each analogy type. That is, sixteen median scores were obtained for each subject (one median for each analogy type). These scores were so variable across subjects that few differences between analogy types were statistically significant. For this reason, and because the pilot experiments were conducted to observe the relative difficulty of analogy types rather than absolute differences between types, the report of results of this experiment will be confined to descriptive, rather than inferential, statistics.

Figure 3 shows the means of these median response times for each analogy



CHAR -- Object-characteristic
O-PUR -- Object-purpose
O-ACT -- Object-action
SPRE1 -- Specific relations (bock 1)
SW-P -- Specific Whole-part

SPRE2 -- Specific relations (block 2)
SUP/S -- Super/subordinate
SYN -- Synonyms
ANT -- Antonyms
W-P -- Whole-part
SP-P -- Specific Part-part

SA/CL -- Same class
SI/SY -- Sign/symbol
CAU/EF --Cause-effect
SEQ -- Sequencing
P-P -- Part-part

Figure 3. Mean solution latencies for each analogy type in Pilot Experiment 1.
Vertical bars show standard errors.

type. Standard error bars indicate the variability of subjects' scores for each type. The analogy types are plotted in ascending order of their mean solution times, ranging from less than 3.5 seconds to over 5 seconds.

The pattern of solution latencies in Figure 3 provides evidence that the two distinctions proposed by Cattell and Bryant may play a role in determining the difficulty of analogy problems. Their distinction between logical and objective types is reflected in faster solution latencies for part-part and whole-part analogies than for same class and super/subordinate types, respectively. Likewise their distinction between whole-part and part-part analogies in the objective category, and between super/subordinate and same class types in the logical category were also demonstrated, by shorter solution latencies for whole-part than for part-part analogies and shorter solutions for the super/subordinate than the same class type.

The distinction between specific and nonspecific analogies was also consistent in two pairs of analogy types in these data; both specific whole-part and specific part-part analogies were more quickly solved than the non-specific versions of these types.

Finally, this figure also indicates that latency differences occurred for analogy types that were intended to illustrate different levels of cognitive sophistication. Object-characteristic, object-action and object-purpose, were solved in approximately 3.5 seconds, whereas analogies using associations thought to be more cognitively sophisticated, such as cause-effect, part-part, and sequencing, required another one or two full seconds of processing time.

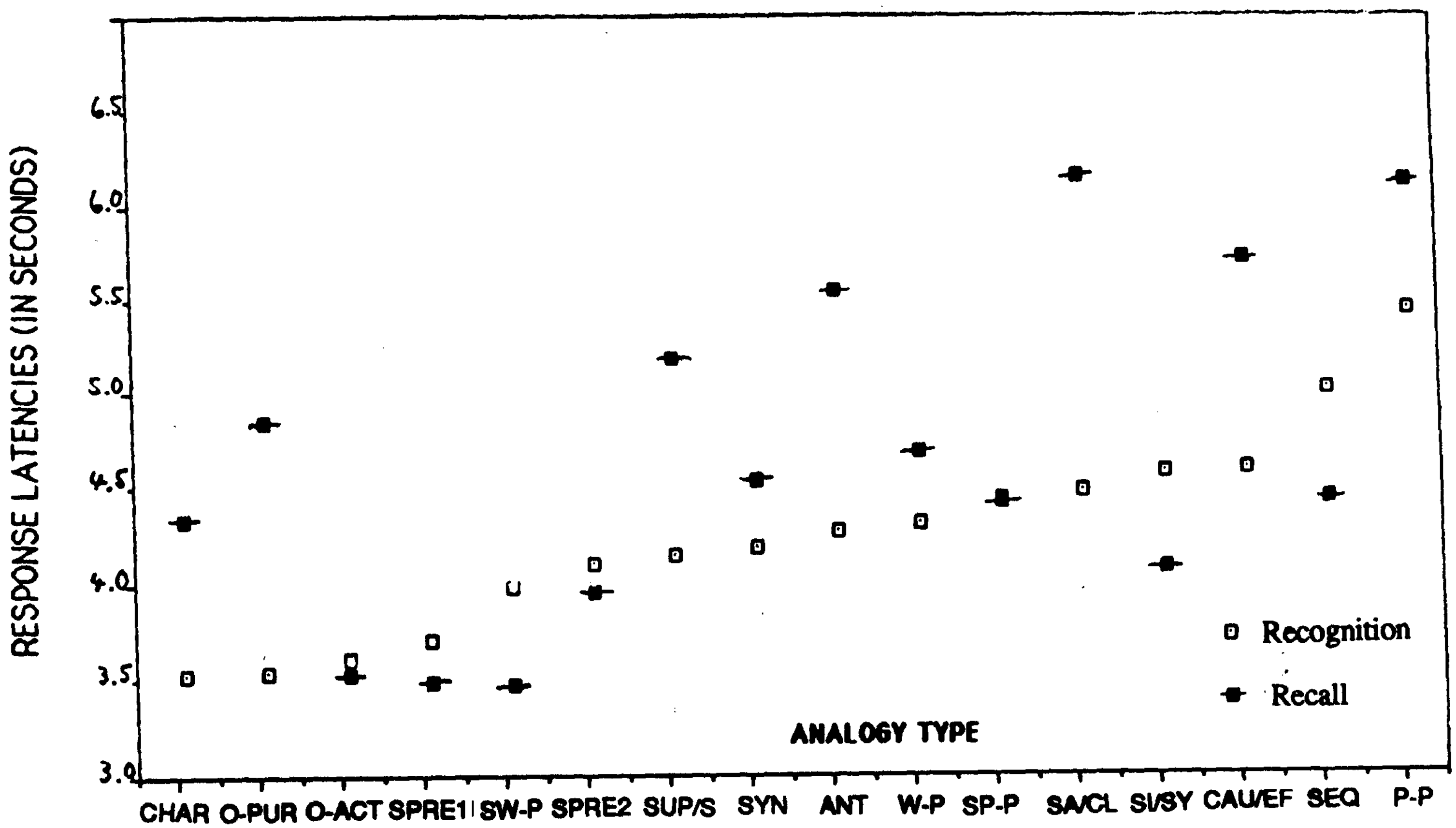
All errors were due to subjects pressing a keypad button which did not correspond to the correct answer provided. The mean error rate was only 7.3 %, and there was no systematic pattern to their distribution across analogy types.

Pilot Experiment 2:
Random Presentation of Analogies in the Free Recall Paradigm

The latency of responses to these problems were initially analyzed as in Pilot Experiment 1. However, in these data the median responses showed too much variability across subjects to allow reliable comparisons across analogy types. As a result, an alternate, items analysis was conducted on these data by first determining the median response time for each analogy problem across the thirty subjects. These medians were then averaged across the five problems within each analogy type to yield a mean median score for each type. Although the calculation of these scores is not like the subjects analysis performed on the data of Pilot Experiment 1, the data from these two experiments are plotted together in Figure 4, in order to illustrate general trends in the data from the two paradigms.

Figure 4 highlights the large variability of latencies across analogy types in Pilot Experiment 2: latency values range from just under 3.5 seconds for object-action analogies to 6 seconds for the cause-effect type. Many of the same types of latency differences found among analogy types in Pilot Experiment 1 re-appear among the data of this experiment. Logical analogy types were solved more quickly than objective types, and within these categories whole-part analogy problems were solved faster than part-part problems, and super/subordinate faster than same class problems. Specific analogies were solved faster than nonspecific versions for both part-part and whole-part types. Finally, as occurred in the data from the recognition paradigm in the first pilot experiment, cognitively simple analogy types seemed to be solved faster than the more sophisticated types, although some notable exceptions exist (eg. sign/symbol analogies were relatively quickly solved).

The compilation of errors in this experiment exposed a series of issues unique to the free recall paradigm. The responses scored as errors in this



CHAR -- Object-characteristic
O-PUR -- Object-purpose
O-ACT -- Object-action
SPRE1 -- Specific relations (bock 1)
SW-P -- Specific Whole-part

SPRE2 -- Specific relations (block 2)
SUP/S -- Super/subordinate
SYN -- Synonyms
ANT -- Antonyms
W-P -- Whole-part
SP-P -- Specific Part-part

SA/CL -- Same class
SI/SY -- Sign/symbol
CAU/EF --Cause-effect
SEQ -- Sequencing
P-P -- Part-part

Figure 4. Mean solution latencies for each analogy type in Pilot Experiment 1 (recognition paradigm) and median response latencies for each analogy type in Pilot Experiment 2 (recal paradigm).

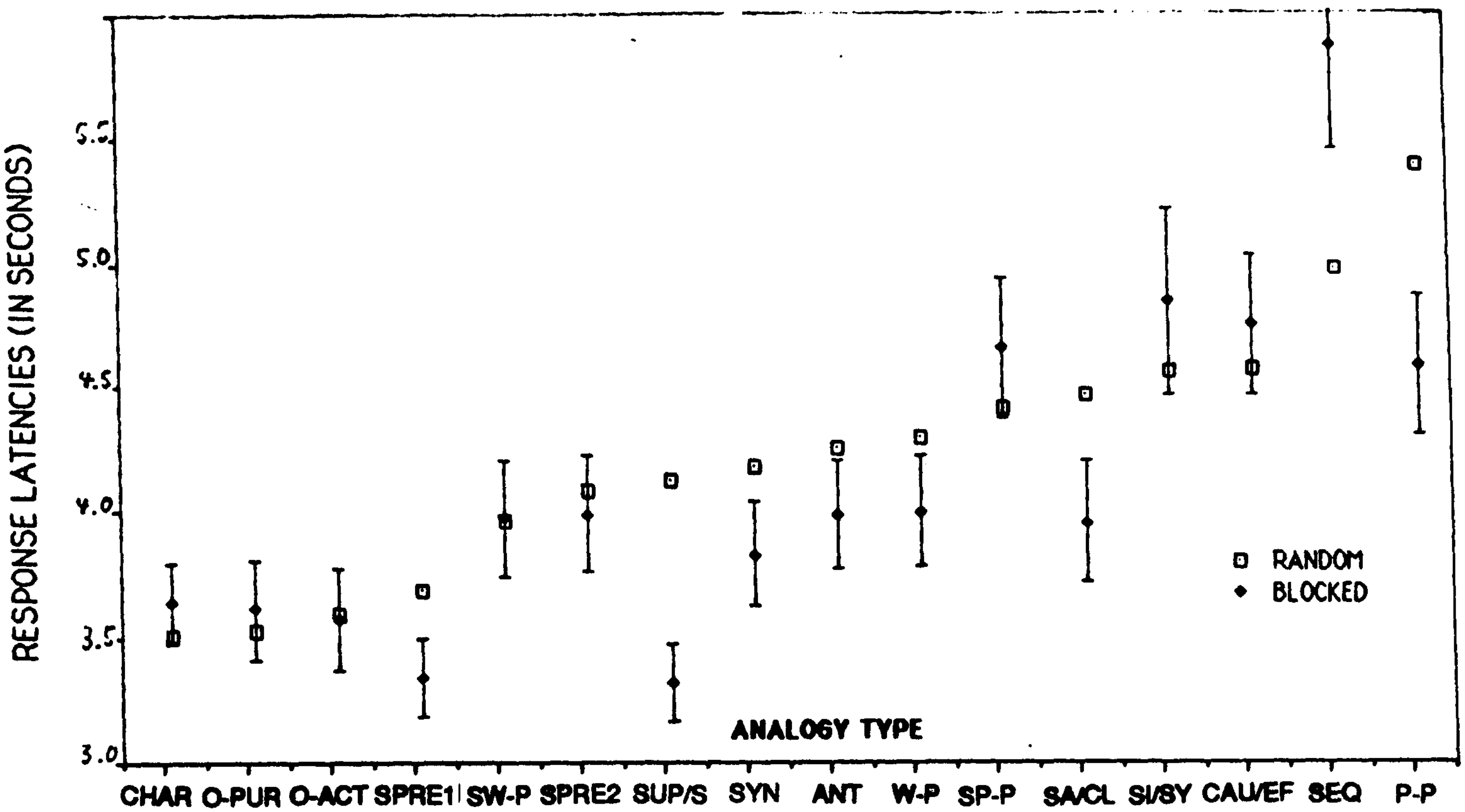
experiment were of three types: i) cases where the subject responded "don't know" to the problem, ii) cases which were uninterpretable utterances, and iii) cases which were judged as not completing the problem according to the association illustrated in the first two words of the stem. Since subjects decided on their own responses, the experimenter's decision as to whether a response correctly completed an analogy was sometimes complicated.

The total errors for some particular problems exceeded a third of the responses. For these stimuli, the latencies of the remaining responses tended to be very high. For this reason, these "error prone" problems were treated as outliers, and their scores were not used in the calculation of the mean median responses of the recall data as they appear in Figure 4.

Pilot Experiment 3: Blocked Presentation of Analogies in the Recognition Paradigm

Dependent variables in this experiment were again the accuracy and speed of responses. The calculation of response latency scores for this experiment employed the same procedure as that of Pilot Experiment 1. Figure 5 shows the mean of subjects' median response latencies to the five exemplars of each analogy type. This figure also includes the results from Pilot Experiment 1 and the order of analogy types plotted in this figure is the same as that for Pilot Experiment 1 in Figure 3. Error bars are plotted for the means of this present experiment only.

Figure 5 shows the same general trends in the data as in the previous two experiments. That is the direction of these differences among analogy types is consistent. Faster latencies were found for logical analogies than objective ones, and both the super/subordinate versus same class distinction, and the whole-part versus part-part distinctions were again confirmed within logical and objective types, respectively. Faster latencies were also found for specific analogies than nonspecific analogies, and the general trend for latencies to lengthen with their



CHAR -- Object-characteristic
O-PUR -- Object-purpose
O-ACT -- Object-action
SPRE1 -- Specific relations (bock 1)
SW-P -- Specific Whole-part
SPRE2 -- Specific relations (block 2)
SUP/S -- Super/subordinate
SYN -- Synonyms
ANT -- Antonyms
W-P -- Whole-part
SP-P -- Specific Part-part
SA/CL -- Same class
SI/SY -- Sign/symbol
CAU/EF --Cause-effect
SEQ -- Sequencing
P-P -- Part-part

Figure 5. Mean solution latencies for each analogy type in Pilot Experiments 1 and 3. Vertical bars show standard errors for blocked condition (Pilot Experiment 3).

greater level of cognitive sophistication was also confirmed in this experiment.

The effect of presenting analogies in blocks according to association type on the latency of their solutions can be observed by comparing the latencies for analogies in Pilot Experiment 1, where no priming manipulation was attempted, to the data of the present experiment. As Figure 5 shows, the effect of priming is not consistent across analogy types, suggesting that the five problems in some analogy types were psychologically more similar to each other than were the five problems of other types. Analogies that showed latency reductions in the blocked condition and therefore appeared to form more psychologically coherent categories included those suggested by Cattell and Bryant's distinctions (i.e. part-part, whole-part, same class, and super/subordinate).

In contrast, the two specific versions of these analogies (i.e. specific part-part and specific whole-part) showed longer latencies in the blocked condition. This finding fueled speculation that specific and nonspecific analogies engage different types of processing. The longer latencies for specific analogies presented in blocks suggests an inability of subjects to process five specific problems as a common type. This perhaps resulted because the specific associations used to match word pairs within each problem were processed in so much detail that subjects were unable to attend to the common defining characteristic among the five problems.

Finally, the observation should be made that the three most quickly solved analogy types in Pilot Experiment 1 showed relatively similar solution times in this blocked condition. This is particularly true of object-action analogies, and suggests that these latency scores showed a floor effect. Priming may not have reduced these latencies because the associations in these analogies are the most readily accessed, quickly used in any experimental condition.

Errors in this experiment were again too low to permit statistical analysis. The rate of errors for individual analogy types varied from 2 % to 8.7 %, around a mean of 4 %.

General Discussion of the Pilot Experiments

Main Findings

Generally, the goals of these experiments were met. Performance differences for different analogy types were demonstrated. The pattern of solution latencies yielded in these experiments suggest that the process of solving analogy problems is influenced by the type of the association they contain. Salient distinctions among these association types include Cattell and Bryant's distinctions, specificity, and a characteristic I have referred to as cognitive sophistication. These distinctions were found consistently in both recall and recognition paradigms. Finally an attempt to prime subjects' processing of these problems indicated which analogy types contained problems that subjects perceived as similar.

The outcomes of the pilot experiments provide support for the recall and recognition paradigms as appropriate vehicles for experimentally investigating the nature of analogy types. Several pieces of evidence provide this support. Subjects were able to interpret instructions reliably, and error rates were low for most analogies. For many, their solution latency relative to other problems was consistent across subjects. Furthermore, both recognition and recall paradigms were successful in distinguishing some analogy types by the latency of their solutions. While the latencies elicited by the recall paradigm were too variable to permit confidence in their values for some problems, these results did indicate which types were most prone to show variability among its five exemplars. The items analysis suggested that much of this variability could be reduced by altering the construction of individual stimuli while maintaining the present paradigm. Further stimulus modifications suggested by these data are outlined below.

Influence of Pilot Work on Stimuli for the Main Experiments

Choice of Analogy Types

The three dimensional model of analogy types. Eight analogy types were used for the main experiments. Seven were from the the pilot work, and a new one was added to complete the three-dimensional model depicted in Figure 1 (p. 6). The model is composed of a 2 X 2 matrix of types on the top of the cube, and two more pairs of types along the vertical dimension on one side of the cube. The three dimensions of this model were based on the analogy types tested in the pilot work that appeared to demonstrate performance distinctions. The two most important dimensions, specificity and inclusiveness, were both based on distinctions tested in the pilot stimuli: specificity was manipulated in two versions each of the part-part and whole-part problems, and the inclusiveness distinction was tested between same class and super/subordinate analogies, and between part-part and whole-part analogies. The final dimension, functional/structural, consisted of three levels, or tiers. The top two tiers were constructed from Cattell and Bryant's objective (whole-part and part-part), and logical types (super/subordinate and same class). The third, lowest tier of this dimension was included because the solution latencies to object-action analogies in the pilot experiments showed them to be more quickly solved than all other analogies in the typology cube. The analogy types on these tiers contain associations which were considered to use cognitive procedures from three levels of relative cognitive sophistication. Although theoretical support for this dimension is tentative, analogy types on this dimension were included in order to test the hypothesis that their relative difficulty is ordered as in Figure 1.

Four critical analogy types on the top tier. The four analogy types on the top tier of the cube in Figure 1 (i.e. part-part, whole-part, specific part-part and specific whole-part) were considered critical problems in the final stimulus set because they form a two-by-two matrix of stimuli illustrating inclusiveness and specificity as two potentially orthogonal dimensions. To illustrate inclusiveness: the whole-part analogy, **boat : mast** as **car : bumper** is an inclusive analogy because the objects **mast** and **bumper** are both included in the objects **boat** and **car**, respectively. This inclusive association contrasts with the noninclusive part-part association in the analogy **leaf : trunk** as **wing : feather**, because in this analogy the objects **tree** and **bird** must be inferred in order to realize the association between the two pairs of words, respectively.

On the other dimension, the degree of specificity is varied within both part-part and whole-part types. In the case of whole-part analogies, specific problems like **hand : palm** as **foot : sole** were created using two pairs of words with similar, very specific relationships between the whole and the part. Likewise, specific part-part analogies were created by matching two parts of one object with two parts of another object, where both pairs of parts form similar relationships with their respective whole objects.

Additional analogy types: the middle and lower tiers. Four additional analogy types comprise two pairs of inclusive and noninclusive analogy types at the two lower tiers of the functional/structural dimension. In the middle tier, the inclusive and noninclusive types are super-subordinate, and same class analogies, respectively. To illustrate, in the super-subordinate analogy **fruit : apple** as **vegetable : corn** the objects **apple** and **corn**, are included in the concepts **fruit** and **vegetable,** and therefore form inclusive associations. In the noninclusive, same class analogy **orange : apple** as **carrot : corn** the objects **apple** and **corn** relate to the first words in their respective pairs only through an inference about their membership to the categories **fruit** and **vegetable**.

These two analogy types were included in the design because they showed relatively consistent latency times across subjects in the Pilot Experiment 1, and they showed evidence that subjects in Pilot Experiment 3 had processed them as cohesive analogy types. Thus, these types appeared to represent psychologically coherent categories that worked well in my paradigms. Further motivation to include them in the design of subsequent experiments arose because, together with the whole-part and part-part analogies, these types illustrate Cattell and Bryant's objective/logical distinction among association types; a distinction that recurred often through the review of the word association literature.

The final pair of analogy types, appearing in the lower tiers of the typology cube are object-action and metamorphosis. Object-action analogies were included in the stimulus set because it was the most consistently, quickly solved analogy type in the three pilot experiments. This suggested that it might represent a psychologically simple or unsophisticated association, and might therefore form a third tier in the functional/structural dimension. Furthermore, object-action and metamorphosis types use a more action-oriented, functional type of association than the other more structurally oriented association types in the cube. This served to introduce the functional/structural distinction as a variable among the analogy types of these three tiers, and provided a preliminary test of their relative accessibility in the context of analogy problem solving.

Like the pair of analogy types on the other two tiers, object-action and metamorphosis types consist of an inclusive and a noninclusive association type, respectively. Object-action analogies, illustrated by **cat : purr** as **dog : bark,** is considered an inclusive type because an action such as **purr** can be considered contained within the object **cat**. That is, no mediating concept must be inferred in order to understand the association. This contrasts with the noninclusive, metamorphosis analogies exemplified by **girl : woman** as **boy : man**. In this analogy, the association between each pair of words must be mediated by the process (in this example, **maturation**) that transforms the first object in a word pair (**girl**) into the second object (**woman**). Note that this inclusiveness distinction is qualitatively different from that between the analogy types on the other two tiers. In the inclusive associations at the other two tiers (i.e.

whole-part and super/subordinate types) inclusiveness is made up of two aspects. One is the fact that one word refers to an object (eg. part) that is contained in the second (eg. whole), and the other is the unmediated nature of the link between the two words. This link is unmediated in the association between **trout** and **fish**, but is mediated by an additional inference (**fish**) required to form the association between **trout** and **salmon**, for example. (See Figure 2 for an illustration of these relationships.) Object-action associations include the unmediated nature, but not the containment aspect, of inclusiveness. While this may seem a flaw in the typology cube, this difference is essentially a result of the functional nature of this lower tier: I propose that actions are contained by their objects as much as a functional entity can be contained by an object. In any case, while this difference regarding inclusiveness along the functional/structural dimension is acknowledged, the lower tier is not a major focus in much of the research in this thesis, as the use of these analogy types is meant to provide a preliminary investigation into these issues.

Modifications to the Construction of Stimuli

The solution latencies yielded by subjects in the pilot experiments revealed a high degree of variability across subjects for some analogy types. Some of this variability resulted from the nature of the words comprising the analogies. In the multiple-choice problems (of the recognition paradigm), an incidental association between a word appearing as a distracter and a word in the analogy stem may increase the difficulty of a problem. An example of this type of association is illustrated in **beaver : work** as **hawk : ____** . The answer **war** completes this sign/symbol analogy as intended. However, some subjects reported solving this problem by reasoning that "beavers work at building dams, hawks work at building nests". Since the word **nest** was an answer alternative provided, many subjects chose this response. Moreover, subjects who chose the correct answer **war** may also have slowed their solution times due to the distracting presence of the **nest** alternative. To address this concern, answer alternatives used in the main experiments were screened to eliminate words that were readily associated with any of the words that make up the analogy problem. This led to an additional design modification for all stimuli. In the pilot experiments, one distracter word in each problem was associated with the first stem word by an association like the one targeted in the problem. However, this was considered a source of distraction that varied between subjects, and it was eliminated in the design of subsequent stimuli.

A second change in the design of the stimulus set in the main experiments was that ten problems were used for each analogy type, instead of five. This resulted in a median value derived from twice as many latency scores as in the pilot experiments, thereby reducing the effect of outlying values on the median of each subject's set of responses, and reducing the variability of latency scores generally.

Pilot Testing Of Stimuli For Main Experiments

Initially, fifteen problems for each of the eight types were composed and pretested. The first three words of these analogies (i.e. the stem) were presented in printed form to approximately forty second year, undergraduate students. These students were asked to respond with written solution words. Their responses were collated to determine which problems most reliably elicited responses consistent with the association depicted in the first word pair. Analogies were considered good stimuli to the extent that they elicited such responses. A second index of goodness was the extent to which subjects showed a consensus as to the actual solution word produced for each problem. High consensus was deemed to indicate goodness. According to these criteria, the ten best problems from each analogy type were chosen as stimuli for the main experiments. In some cases minor changes were made to ensure subjects would not misinterpret the analogy; words which had proven to be ambiguous to some subjects were substituted with words that subjects would interpret more reliably. The final bank of ten stimuli from each of the eight types is presented in Appendix F.

In the multiple choice version of the tests (i.e. those used in the recognition paradigm), a different set of four answer alternatives was constructed for each problem. Each set of alternatives consisted of one word which correctly completed the analogy (the correct answer) and three distracter words. The word chosen as the correct answer was the one that subjects most frequently offered as the solution in pilot testing. Distracter alternatives were chosen from a bank of words elicited from the responses of a second group of undergraduate pilot subjects who performed a free word association task. These subjects were presented with the third word from the analogy stem of each of the original set of approximately 120 analogies. Subjects were instructed to write the first word associate that they thought of in response to each of the 120 words. Distracter words for the final set of analogy problems were chosen from these responses. In no case was a distracter word for a problem chosen from the word associates given to the third word of that same problem. This method ensured that these distracters were all highly familiar and frequently used words. They also tended to be highly concrete in nature, and over-represented nouns in the English language. From several hundred free association responses collected, 240 were chosen as the distracters in the analogies used as stimuli in the main experiments, and another 48 were used as the distracters in the practice test problems.

Four versions of the multiple-choice test were constructed in order to counterbalance the position of the correct answer across subjects. For each analogy, the correct answer occupied a different position among the answer alternatives in each of the four test versions. Within each test version, the answers in the ten problems of each analogy type occupied each of the four answer positions 2 or 3 times. The 240 distracter words were assigned randomly to the remaining answer positions in each analogy.

In order to guard against the occurrence of incidental associations between the analogy stem and the distracter words assigned to that problem, two judges inspected these problems, complete with the initially assigned distracter words. These judges identified distracter words which, in their view, bore an incidental association to the analogy stem or to the correct answer for that analogy. Suspect words were reassigned to positions in other analogy problems within the same test version. Only one version of the multiple-choice practice test was generated, and it was similarly designed.

In the free recall version of the test, the set of problems used as stimuli consisted of the same analogy stems (i.e. the first three words in each problem) used in the multiple choice condition, but were presented without answers or distracters. Only one test version was necessary.

CHAPTER FIVE
EXPERIMENT 1: INITIAL DEMONSTRATION AND BASELINE DATA

Goals

In this experiment my eighty analogy problems were presented in a completely random order. The goals of this experiment centered on testing hypotheses about inclusiveness, specificity, and the processing differences between the two experimental paradigms. A fourth, speculative hypothesis focussed on the functional/structural dimension of the typology cube in Figure 1. In addition to these goals, this study is of special significance for my thesis because its findings were used as baseline data against which to compare the results of subsequent experiments.

Experiment 1A and 1B used the recognition and free recall paradigms described in Chapter Four, respectively. The method, results and discussion of these two experiments are presented together throughout this chapter.

Experimental Hypotheses

The hypotheses described here are central to many of the experiments in my thesis, and so are discussed below in some detail. The rationale for my hypotheses results directly from the processing model I have proposed to account for the cognitive activities involved in problem solving. According to this model, the cognitive procedures that represent associations are formed in the first word pair and applied to the third word through a series of processing components described in Chapter Three. These will be reiterated here, prior to the detailed discussion of each hypothesis, in order to review the processes underlying these hypotheses.

In the earliest of these processing components, inference, the defining characteristic of the association is determined through a process whereby the system tests the first word pair in the problem for the presence of various types of associations. As a consequence, the sequence of associations types tested in any particular problem depends on the nature of the associations type present in that problem. For any problem, in this sequence the subject must i) activate representations of various types of associations in an attempt to recognize their presence in the word pair, and ii) activate word attributes that might form these associations in the word pair. Since it is assumed that the order of the association types tested is determined by their cognitive sophistication or the frequency of their use, this sequence is longer for more complex, rarely used associations. This supports the most general hypothesis in this thesis: that different association types consist of distinguishable cognitive procedures, and that these processing differences will result in a different characteristic solution latency for each association type.

A more specific hypothesis which follows from the processing at this inference component is the inclusiveness hypothesis. This hypothesis predicts that because noninclusive associations require extra inferential steps during the inference process, they should consume more time at this component and should therefore produce longer solution latencies than inclusive associations. A second hypothesis arising from the processing of the inference component is the functional/structural hypothesis. It proposes that the time required to test for the presence of each association type in a word pair is based on the cognitive sophistication and/or the frequency of use of that association type.

Later, the cognitive processing at the mapping component forms the basis of the specificity hypothesis. In this component the attributes of the analogy's third word are activated to determine how closely these attributes match those activated in the first word. If the sequence of attributes activated in these two words is similar, the analogy is processed as a specific one, and solution latencies are expected to be relatively fast, according to the specificity hypothesis.

Lastly, speculation concerning the role of the two justification components forms the basis of a hypothesis regarding the relative speed of problem solving in the recall and recognition paradigms. Each of these hypotheses will be now be further detailed, in turn.

Inclusiveness. In the inference component the association between the first pair of words, is identified and a representation of the cognitive activities involved in finding it is formed. This procedure may include the formation of the association found in the word pair as well as mistaken attempts to recognize other association types. The cognitive activities of the inference component may include activating attributes, and drawing inferences between them. The inclusiveness hypothesis states that extra time is spent processing noninclusive associations at this inference component because they require an extra step to draw inferences between the words, compared to inclusive associations. To illustrate: in inclusive analogies such as the whole-part example **hand : palm** as **foot : sole**, the nature of the association between **hand** and **palm** is relatively immediate because a **palm** is physically contained in the object **hand**. In contrast, a noninclusive association requires the subject to infer an additional, mediating concept. For example, the part-part analogy **root : stem** as **wing : beak** requires this additional step during the inference component because **plant** must be realized as a common associate to the first pair of words. The extra processing required to form this extra step is the basis for the inclusiveness hypothesis. It should be noted that this extra inferential step must also occur during the later application component where, in the above example, the concept **bird** must be realized before a solution word can be generated. My processing model locates the extra processing time demands of noninclusive associations at the earlier, inference component because it assumes that the process of forming this association is more time consuming than the process of applying it in a second context. This assertion is consistent with the procedural nature of the model which holds that the entire pattern of cognitive activity formed to represent the initial association is replicated automatically in subsequent cases.

Hypothesis 1.1: Inclusive problems will be more easily solved than noninclusive problems. This effect will occur with both specific and nonspecific analogy problems, and in both recall and recognition paradigms.

Specificity. The processing advantage hypothesized for specific analogies begins at the mapping component and enhances processing at the subsequent two components (application and justification). Mapping consists of the search for attributes in the third word to match those attributes of the first word that were found relevant to the initial association. For specific analogies, this search is more quickly performed because the cognitive activity used for discovering the attributes in the first word can be repeated successfully with the third word. If many common attributes are found in the third word, the mapping component will discover this similarity quickly. For example, in the the specific whole-part analogy **hand : palm** as **foot : sole**, the word **foot** contains many of the attributes found in **hand** which are relevant to the association between **hand** and **palm**.

This processing advantage for specific problems continues in the application component because once this detail has been mapped, the specific characteristics of the association between the first pair of words can be applied to this third word. It is assumed that this specific association evokes a relatively narrow propositional fan in the subject's memory and that the relatively few word associate(s) in this fan is/are quickly generated. Finally, since this propositional fan generates relatively few associates, the justification process is also accelerated or eliminated.

To illustrate the nature of this efficiency, consider that the set of words that could complete the analogy **hand : palm** as **foot :** _____ using the specific association illustrated by the first word pair includes the words **sole** and **arch**, but excludes all other parts of **foot**. In contrast, in a nonspecific problem such as **head : ear** as **foot :** ____ , the association-relevant attributes in the first word can not be specificly matched in **foot**, and so the association is applied as a nonspecific whole-part type. This results in the use of a relatively wide propositional fan where every part of **foot** can be generated as a associate, including **heel, ball, ankle, toe,** etc.

Hypothesis 1.2: Specific problems will be more quickly solved than nonspecific problems. This effect will persist across both levels of the inclusiveness dimension, and in both recall and recognition paradigms.

Recall/Recognition. Late in the processing model, at the justification components, processing differences between the two paradigms (recognition and recall) may also become manifest as differences in the overall solution latencies of the problems. Solution latencies are expected to be shorter in the recognition paradigm for two reasons. First, the recall paradigm demands that subjects perform the extra process of generating the solution word aloud. This is expected to lengthen the latencies of solutions in the recall paradigm for all analogy types. Secondly, the presence of the answer alternatives in the recognition paradigm allows subjects to expedite their justification of a solution response from among internally generated alternatives. They are able to do this by examining the provided answer alternatives and using them to help decide on their final response. This process is expected to result in shorter latencies in the recognition paradigm, especially for problems with many potential answers generated at the application component, such as nonspecific problems.

Hypothesis 1.3: Solution latencies in the recall paradigm will be longer than in the recognition paradigm.

Functional/Structural. The following hypothesis concerning the functional/structural dimension is a weak one, and latency differences between analogies at different levels of this dimension are not closely analyzed in this thesis. Like the inclusiveness hypothesis, this hypothesis is based on the assumption that in the inference component cognitive procedures require different amounts of processing time for different association types. As mentioned above, some of the steps in these procedures may involve the consideration and rejection of associations which are highly accessible in memory but are not relevant to the particular problem, and are therefore not present in the word pair. The functional/structural hypothesis proposes a basis for the relative accessibility of different association types in memory. The hypothesis states that the accessibility of association types is ordered according to the vertical dimension of the typology cube in Figure 1: object-action and metamorphosis types are expected to be most accessible and yield the fastest solution latencies, while part-part and whole-part types are expected to be least accessible and slowest to process. This hypothesis follows the rationale that the relative accessibility of an association type is determined in part by the amount of experience the subject has using it. Accordingly, associations acquired by young children, such as the object-action association, should be most readily used because they are cognitively simple and/or because they have been frequently used in the subject's everyday thinking. Conversely, associations representing categories or the analysis of objects into parts are acquired at a later age, may be less common in subjects' daily lives, and are therefore expected to be less quickly used in the context of my analogy problems.

Hypothesis 1.4: The order of the levels of the functional/structural dimension depicted in Figure 1 will be reflected by the solution latencies of these analogy types. Lower, functional levels will evoke faster solutions. This will persist for both inclusive and noninclusive relations and will occur in both paradigms.

Method

The recognition and recall paradigms outlined in the general method described in Chapter Four were used in Experiments 1A and 1B, respectively. The materials used were the ten analogy problems from each of eight analogy types, also described in Chapter Four. The practice tests contained sixteen problems; two of each of the eight analogy types used. Each experiment used twelve male and twelve female subjects drawn from the same subject pool used in the Pilot Experiments.

Results

Experiment 1A: Recognition Paradigm

Scoring

The two dependent variables measured in this experiment were decision accuracy and decision latency. Errors occurred when subjects gave incorrect responses or failed to respond. In this experiment errors were negligible (i.e. less than 2%) and were not further analyzed. Analysis of the data from this experiment focussed on the latencies of correct responses. For each analogy type, ten such responses (fewer than ten when an incorrect response was made) were obtained from each subject. From these data a median response latency for each analogy type, for each subject, was computed. This analysis will be referred to as the subjects analysis. The means of these medians, collapsed across subjects, are shown in Table 5 and Figure 6.

The response latencies in this experiment were also analyzed in a second way to test their consistency across the ten examples of each analogy type. For this purpose, a median latency score was computed for each problem, based on the responses from the twenty-four subjects. These medians, averaged across the ten problems of each analogy type, are also presented in Table 5 and are referred to as the means from the items analysis.

Analyses

Statistical analyses on the means from items and subjects analyses were performed, and are presented below. For these analyses, and all others reported in this thesis, an alpha level of .05 was used unless otherwise specified.

The means from the subjects analysis are plotted in Figure 6. This figure shows that inclusive whole-part analogy problems were more quickly solved than noninclusive part-part problems, and that the specific analogies were more quickly solved than the nonspecific versions of these types. To statistically test these effects of specificity and inclusiveness, a 2 X 2 ANOVA was performed on the analogy types occupying the top tier of the typology cube in Figure 1. This analysis confirmed a main effect for inclusiveness, $\underline{F}(1,23) = 30.6$, $\underline{MS}_e = 370{,}877.2$, and for specificity, $\underline{F}(1,23) = 31.9$, $\underline{MS}_e = 349{,}862.9$, with no interaction between these factors, $\underline{F} < 2$. The sources table for this ANOVA and all others reported in this thesis appear in Appendix Z.

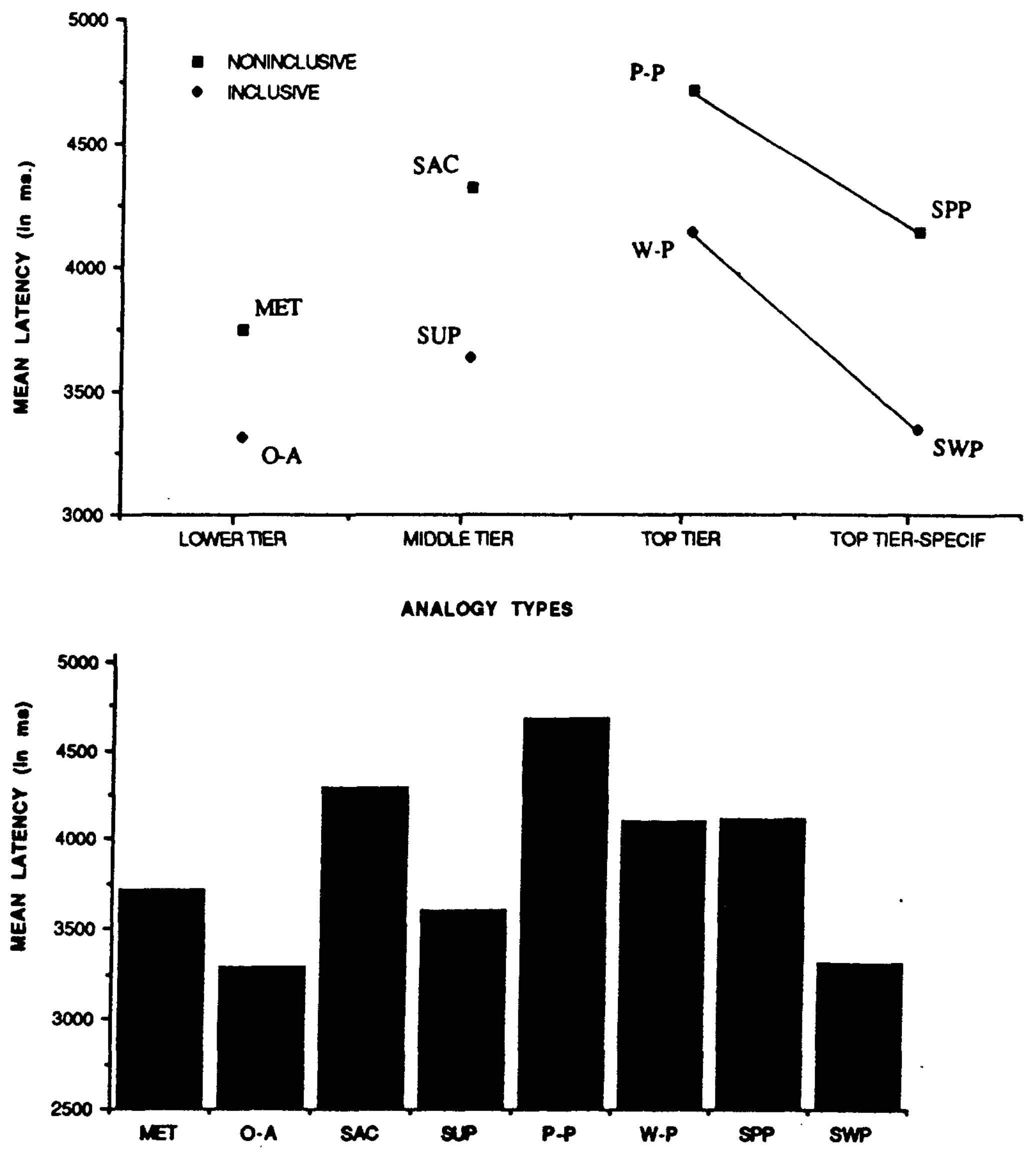
The means of the item analysis are shown in Figure 7. These data were submitted to a similar 2 X 2 analysis of variance. This analysis among the four analogy types on the top tier of Figure 1 showed an effect for inclusiveness, $\underline{F}(1,36) = 13.2$, $\underline{MS}_e = 371{,}434.6$, and for specificity, $\underline{F}(1,36) = 13.9$, $\underline{MS}_e = 371{,}434.6$, and no interaction was found, $\underline{F} < 2$. In Figure 7, a comparison of

Table 5

Mean Solution Latencies From Subjects Analysis and Items Analysis of Recognition Data From Experiment 1

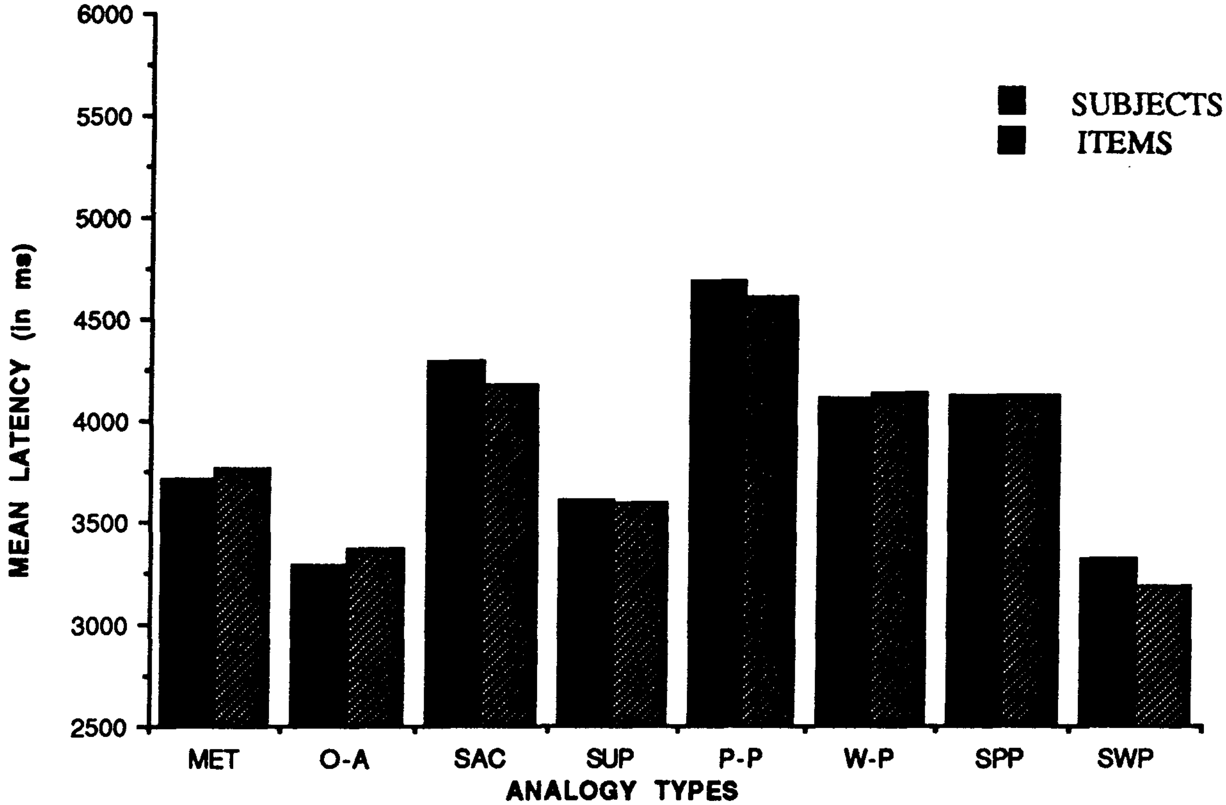
Analysis	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
Subjects:	3717	4291	4686	4115
Items:	3757	4168	4603	4121
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
Subjects:	3286	3603	4109	3316
Items:	3370	3590	4138	3182

note. latencies are given in milliseconds.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 6. Mean solution latencies from recognition paradigm in Experiment 1. Two plots of these data are presented. The top panel highlights the significant latency differences for analogy types at different levels of the inclusiveness dimension (distinguished by different symbols), and the specificity dimension (between analogy types depicted by connected symbols). The bottom panel presents these data as they are presented when compared with other experimental conditions.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 7. Mean solution latencies from subjects analysis and items analysis of recognition data from Experiment 1.

these means with the results for the subjects analysis shows similar latencies. Since the subjects and the items analyses showed similar results, further statistical tests were only performed on the more commonly used subjects analysis.

In order to determine which particular pairs of analogy types yielded significantly different latency scores, a series of Newman-Keuls multiple comparisons were performed on the means from the subjects analysis. These comparisons tested each adjacent pair of analogy types, as depicted in the model in Figure 1. The results of these comparisons, presented in Figure 8, again confirm consistent specificity and inclusiveness effects. Pairs of analogies distinguished on the inclusiveness dimension showed that inclusive types (whole-part) were more quickly solved than noninclusive types (part-part), and pairs of analogies distinguished by specificity showed significantly shorter latencies for specific problems.

An additional 3 X 2 ANOVA was performed on the six non-specific analogy types on the front face of the cube in Figure 1. This analysis tested the consistency of the inclusiveness effect across the three levels of the functional/structural dimension, and compared the mean latencies of analogy types at the three levels of this dimension. In Figure 6, noninclusive analogies appear to elicit longer solution latencies than the inclusive analogies, across all three levels of the structural/functional dimension. The ANOVA confirmed this effect, $\underline{F}(1,23) = 19.4$, $\underline{MS}_e = 593819.8$. The main effect of the functional/structural dimension was also significant, $\underline{F}(2,46) = 16.0$, $\underline{MS}_e = 603937.4$, thereby confirming the trend indicated in Figure 6, namely that the difficulty of the analogies increases across the tiers of the typology cube. There was no interaction between these factors, $\underline{F} < 2$, indicating that the effect of inclusiveness was consistent across the levels of the functional/structural dimension. Results of Newman-Keuls analyses between pairs of these means are also portrayed in Figure 8, and confirm the results of the ANOVA for most

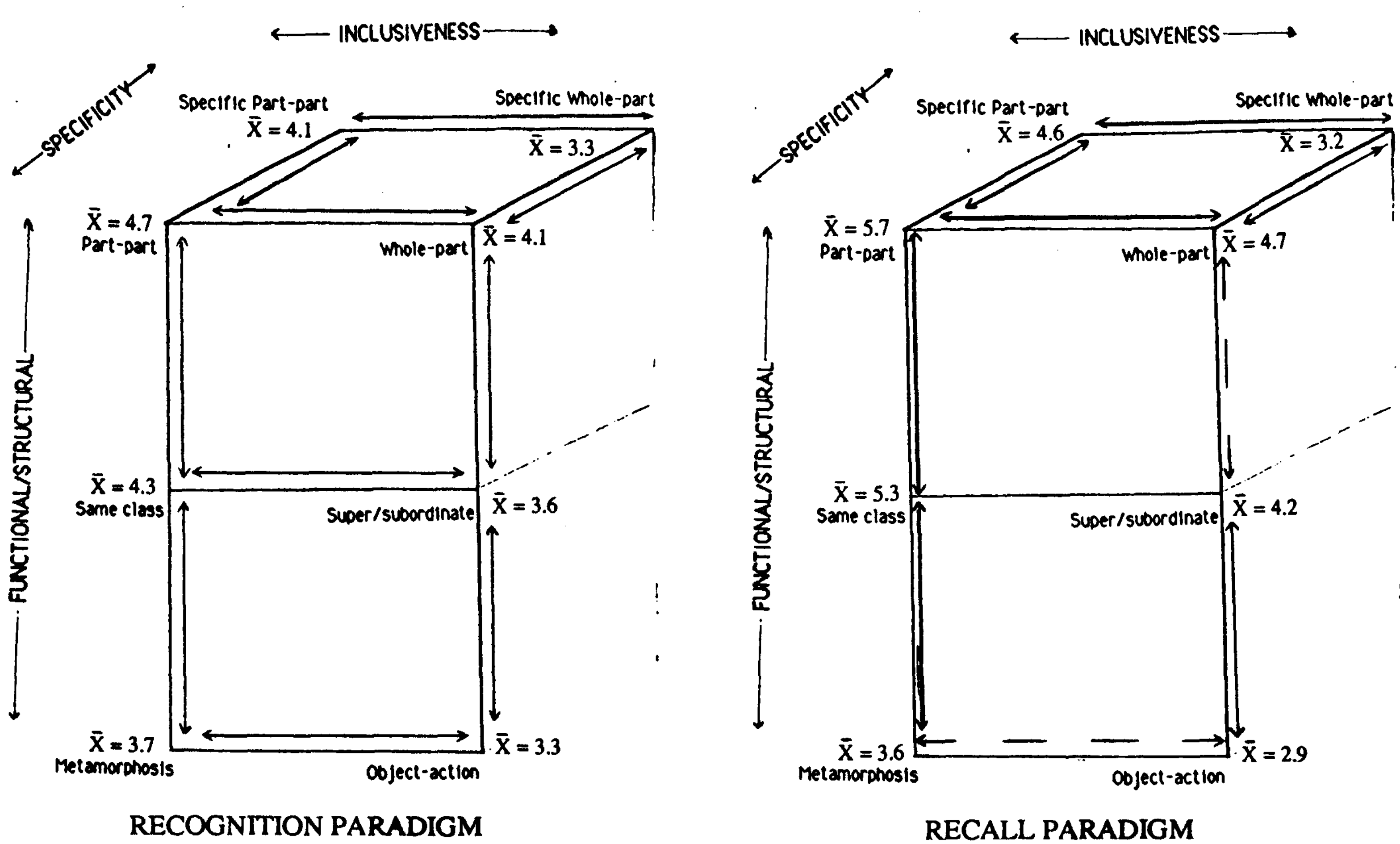


Figure 8. Results of Newman-Keuls multiple comparisons in Experiment 1.
solid lines indicate significant differences between means;
broken lines indicate nonsignificant differences (alpha = .05)

note means are expressed in seconds.

pairs of analogy types.

Experiment 1B: Free Recall Paradigm

Scoring

Only problems for which subjects gave an acceptable response were used to derive their median latency scores. Subjects' responses were judged acceptable if they completed the analogy problem with an associate to the third word which was consistent with the association type illustrated in the first word pair. Judgements as to the acceptability of responses were initially made by a single scorer. In an attempt to determine how the median latencies derived from this original scoring would compare to the medians derived when other scorers judged acceptability of answers, a second scoring method was used, and yielded an alternate set of data. This alternate scoring of the data was achieved by presenting a list of the responses considered controversial by the original scorer to two additional judges. For cases where both additional judges disagreed with the judgement of the first scorer, the status of the answer was changed (i.e. was, or was not classified as an error). The mean median scores resulting from this alternate method of scoring are listed in Table 6 together with those for the original subjects analysis. As the table shows, these two sets of means are very similar to each other and so provided confidence in the reliability of the original scoring. Statistical analyses of the data from the alternate scoring method (appearing in Appendix G) confirms its similarity to the original data set.

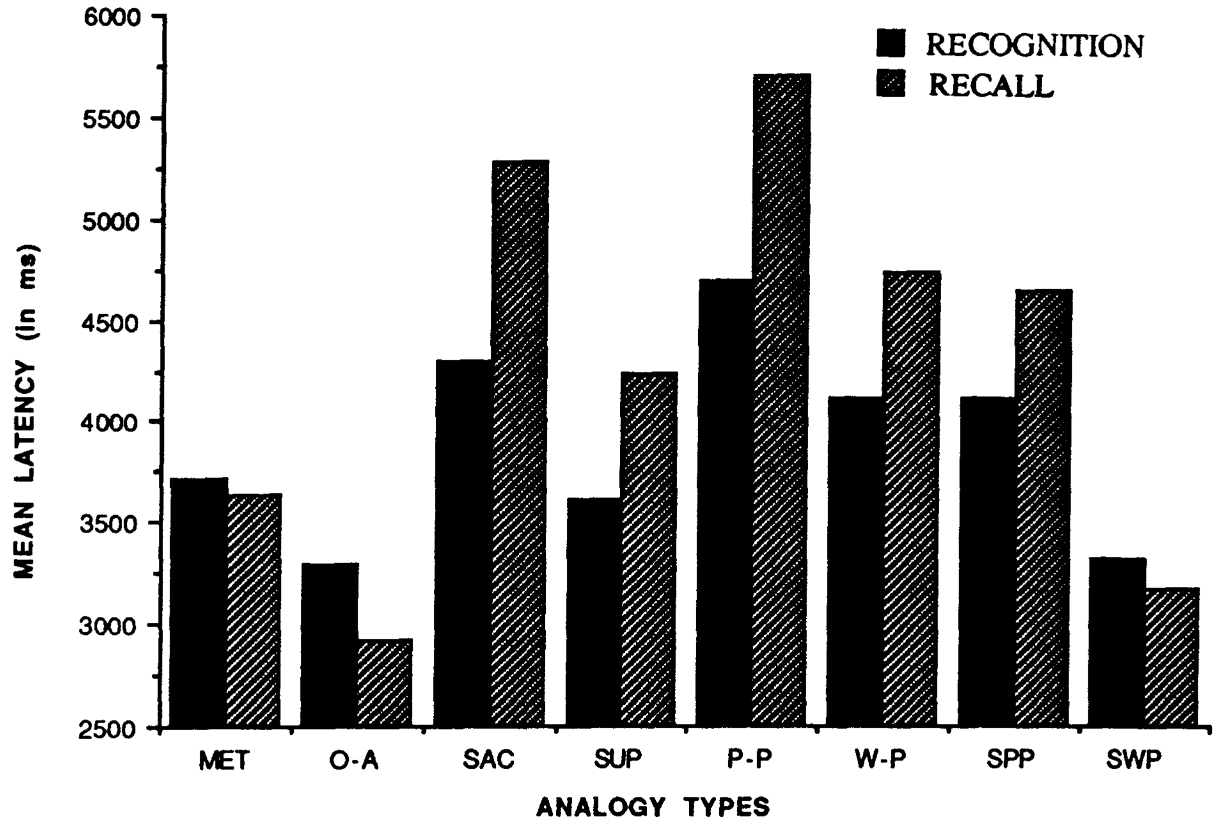
Solution latencies from this paradigm were summarized in the form of each subject's median response latency to the correctly solved problems of each analogy type. The mean of these median latencies collapsed across subjects are presented in Table 6 and Figure 9. These data are referred to as the original subjects analysis for this experiment.

Table 6

Mean Solution Latencies From Subjects Analysis, Alternate Judges Analysis, and Items Analysis of Recall Data From Experiment 1

Analysis	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
Subjects:	3630	5279	5695	4646
Judges:	3628	5248	5605	4704
Items:	3434	4917	5267	4643
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
Subjects:	2919	4225	4736	3179
Judges:	2928	4185	4736	3179
Items:	2825	3599	4327	2944

note. latencies are given in milliseconds.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 9. Mean solution latencies from subjects analysis of recognition and recall data from Experiment 1.

Analysis of Latencies

The means of subjects' median scores in Table 6 and Figure 9 reveal effects of specificity and inclusiveness similar to those found in the recognition paradigm. As in the recognition paradigm, a 2 X 2 ANOVA was performed on the four analogy types at the top tier of the cube in Figure 1. Among these types, both main effects of inclusiveness and specificity were confirmed, $F(1,23) = 35.7$, $MS_e = 1003809.4$, and $F(1,23) = 33.6$, $MS_e = 1195430.0$, respectively, and no interaction was present, $F = 2.0$. A series of Newman-Keuls multiple comparisons was performed on the means from these four analogy types, and confirm these effects for all relevant pairs of analogy types. The results of these comparisons also appear in Figure 8.

An items analysis like that performed on the data from the recognition paradigm was also performed on these data. The means from this analysis appear in Table 6. As these statistics show, these means were again very consistent with those from the subjects analysis. Readers interested in further details about this similarity are directed to Appendix G where the results of an ANOVA performed on the data from the items analysis are reported.

As was done for the data of the recognition paradigm in Experiment 1A, a 2 X 3 repeated measures ANOVA was performed to test the effect of inclusiveness across the three pairs of means appearing on the front face of the typology cube in Figure 1, and to compare the solution latencies for analogies at the three levels of the functional/structural dimension. This ANOVA yielded significant main effects for both inclusiveness, $F(1,23) = 89.5$, $MS_e = 331019.1$, and the functional/structural dimension, $F(2,46) = 38.0$, $MS_e = 1297997.0$, and no interaction between these factors, $F = < 1$. This lack of interaction confirms the consistency of the inclusiveness effect across the three levels of the functional/structural dimension. Newman-Keuls comparisons presented in

Figure 8 also confirmed many of these effects. The latencies of all adjacent pairs of analogies on the typology cube in Figure 1 were found to be different from each other, except the comparison between metamorphosis and object-action types.

Errors

Errors were analyzed in Experiments 1A and B for two reasons. First, this experiment provides a baseline error rate which can be compared to error rates of future experiments. These will be used as a general index of task difficulty across experiments. Experiments with larger error rates may be viewed as involving more difficult tasks. Secondly, the relative difficulty of different individual problems, and of problems from different analogy types might be indexed by comparing their error rates within experiments.

In the recognition paradigm errors occurred when subjects pressed an incorrect answer key on the computer keypad. This occurred for only 1.7% of responses. In the recall paradigm, errors occurred when subjects failed to respond to a problem, or when responses were judged to be associations of a different type than that demanded by the problem's first word pair. The rate of missing responses was 1.7%; the total error rate was 10.5%. The total number of errors for each analogy type in both paradigms is presented in Table 7.

Analysis of the error data confirm many of the findings from the analysis of solution latencies. In general, analogy types with longer latencies tended to also elicit more errors. In the data from the recall paradigm this relationship yielded a correlation coefficient of .81. Too few errors were committed in the recognition paradigm to warrant a similar analysis. This relationship was also confirmed by the presence of a specificity effect and an inclusiveness effect among these error totals. The combined error rates of Experiments 1A and 1B (i.e. collapsing across the two paradigms) revealed that 50 errors came from specific analogy types and 79 came from nonspecific types. These error rates

Table 7

Total Errors for Each Analogy Type in Experiment 1

Association Type	Errors in Exp't 1A	Errors in Exp't 1B
Metamorphosis	5	32
Object-action	6	7
Same Class	4	32
Super/subordinate	3	15
Part-part	6	50
Whole-part	2	21
Spec. Part-part	5	36
Spec. Whole-part	1	8
Total	32	201

also showed inclusive analogies accounted for 63 errors, while the noninclusive analogies accounted for 170. Chi square analysis of these distributions confirm both specificity and inclusiveness effects, $\underline{p} < .02$. These analyses are consistent with the effects of specificity and inclusiveness found in solution latencies; subjects had more difficulty with nonspecific analogy types than specific ones and noninclusive problems were more difficult than inclusive ones.

Comparison Between The Two Paradigms

Medians Analysis

The latencies from the recognition and free recall paradigms were compared to determine if the free recall task presented subjects with additional time consuming demands. Figure 9 appears to show that the recall task increased processing demands for several analogy types, especially for part-part and same class types. However, Hypothesis 1.3 predicted that this increase would occur generally, for all analogy types.

In order to explore the effect of the different paradigms on the four critical analogy types on the top tier of the cube in Figure 1, a 2 X 2 X 2 ANOVA was conducted on the solution latencies of the relevant conditions. Since no main effect of the two paradigms was found, $\underline{F} = 2.4$, Hypothesis 1.3 was not supported. However, the analysis showed an interaction between paradigms and specificity, $\underline{F}(1,46) = 5.8$, $\underline{MS}_e = 772646.9$, finding that the processing advantage for specific problems relative to nonspecific problems was enhanced in the recall paradigm. Another two-way interaction was found between the two paradigms and the inclusiveness dimension, $\underline{F}(1,46) = 5.0$, $\underline{MS}_e = 687343.3$, indicating that the additional time required to solve the noninclusive (part-part) analogies relative to the inclusive (whole-part) analogies was greater in the recall paradigm, than the corresponding latency difference in the recognition paradigm. In summary, both of these interactions showed that the recall paradigm led to increased solution latencies for more difficult analogy types. That is, the recall paradigm increased latencies the most for nonspecific and noninclusive analogies, which had produced relatively long latencies in the recognition paradigm.

A 2 X 3 X 2 mixed design ANOVA was performed on the six analogy types on the front face of the typology cube in Figure 1 in order to compare the solution latencies from the two paradigms across the three tiers of the functional/structural dimension, and between the two levels of the inclusiveness dimension among these six analogy types. This analysis failed to find a main effect of paradigm type, $F = 2.2$, but showed interactions between the paradigms and the functional/structural dimension, $F(2,92) = 8.7$, $MS_e = 945152.0$, and between the paradigms and inclusiveness, $F(1,46) = 4.7$, $MS_e = 463204.1$. The inconsistency of this effect of paradigms across analogy types motivated a further statistical analysis designed to determine whether the size of this effect was related to the general difficulty of analogy types. For each analogy type, the latency increase found in the recall paradigm relative to the recognition paradigm was compared to the magnitude of the latency scores from the recognition paradigm. A correlation between these values across the six analogy types yielded a correlation coefficient of .85 ($r = .87$ when all eight analogy types are included). This finding confirms the trend found in the earlier 2 X 2 X 2 ANOVA; solution latencies are quicker in the recognition paradigm especially for the most difficult analogy types.

Exceptional Analogy Problems

Two types of exceptional problems were identified and studied: outliers and inconsistent problems. Outliers were analogy problems which elicited unusually short latencies in both recognition and free recall paradigms in Experiment 1, or unusually long latencies in both paradigms. Inconsistent problems were those that elicited unusually long latencies in one paradigm and/or unusually short latencies in the other.

The identification of these exceptional problems was performed to discover analogy problems that produced latencies unlike those of the others in the category. The exceptional problems identified here are later compared to the results of similar analyses in other experiments to determine whether they were consistently exceptional problems across experiments. Other experiments in this thesis where comparable analyses were made include Experiment 2 where exceptional problems were observed in the same way as reported here, and Experiment 5 where subjects were asked to provide an index of similarity among problems by performing a sorting task.

To identify the most outlying problems, all problems whose median response times across the 24 subjects was more than 1.5 standard deviations[2] away from the mean for that analogy type (i.e. $Z < -1.5$, or $1.5 < Z$) were identified. This analysis revealed that three problems were outliers in the data from both paradigms. These outliers are listed in Table 8. Please note that each of these problems came from a different analogy type.

Inconsistent problems were discovered by comparing the standard deviations of the latencies for each analogy (Z-scores) in the two paradigms. If a problem's solution latency relative to others in its type differed greatly between recognition and recall paradigms (i.e. by more than 2 Z^2), that analogy was identified as an inconsistently solved problem. These inconsistent problems, the degree of the difference in their solution latencies between paradigms, and the analogy type they represent, are presented in Table 8. The table shows that six such problems were discovered, from five different analogy types.

Discussion

The goals of this first experiment were largely fulfilled. The experiment was designed to test three hypotheses corresponding to the three dimensions of the

Table 8

Outlying and Inconsistent Problems in Experiment 1

Outliers

Stimulus Stem	Answer Alternative	Relation Type	Z-scores(1A,1B)
pool cue : chalk :: skis :	wax	spec. whole-part	2.25, 1.5
knife : fork :: saucer :	plate	part-part	-1.55, -2.2
plaster : crack :: stocking	run	object-action	2.55, 1.77
acorn : oak :: bulb :	tulip	metamorphosis	2.58, 2.25

Inconsistent Items

Stimulus Stem	Answer Alternative	Relation Type	Z-scores(1A,1B)
school : gym :: restaurant :	kitchen	whole-part	-1.69, 2.29
team : player :: army :	soldier	spec. whole-part	-.76, 1.45
pork : beef :: shrimp :	scallops	same class	-.85. 1.73
Latin : French :: New Zealand	Peru	same class	1.87, -.77
plaster : crack :: stocking :	run	Object-action	2.55, .52

notes. 1A indicates recognition paradigm in Experiment 1
1B indicates recall paradigm in Experiment 1

typology cube in Figure 1, and to compare solution latencies across the two paradigms. In the first section of this discussion the results are reviewed in light of the hypotheses. The second section presents a discussion of the relationship between inclusiveness and specificity dimensions, and a discussion comparing the results from the two paradigms.

Review of Main Findings

Analogy Dimensions

Hypotheses 1.1 and 1.2 regarding the inclusiveness and specificity dimensions were confirmed by both paradigms in this experiment. Inclusiveness resulted in shorter solution times for whole-part problems relative to part-part problems in both pairs of analogy types on the top tier of Figure 1, and specific analogy problems were solved faster than nonspecific ones among these same analogy types. As well, the consistency of the inclusiveness effect extended to both pairs of analogy types on the lower two tiers of the functional/structural dimension. Finally, the error pattern among analogy types in this experiment supported both the inclusiveness and specificity hypotheses.

The tentative Hypothesis 1.4 regarding the functional/structural dimension was also supported. Differences in latency times were found among analogy types on this dimension in both recall and recognition paradigms; mean latencies were ordered as depicted in the vertical dimension of the typology cube in Figure 1.

Paradigms

Hypothesis 1.3 proposed that analogies presented in the free recall paradigm would be solved more slowly than when they were presented in the recognition paradigm. This was not entirely confirmed by Experiment 1. While subjects required more time to solve some analogy types in the free recall version (eg.

part-part and same class types), this effect was not large, and not consistent across analogy types. This indicates that the task demands requiring subjects to generate their own solution words and produce a spoken response did not add significantly to the general difficulty of all analogies.

However, solution latencies interacted between paradigms and both specificity, and inclusiveness. The nature of these interactions showed that the more difficult analogy types (i.e. nonspecific and noninclusive types) were processed differently in the two paradigms. The discovery that latencies for these difficult types were longer in the recall paradigm than in the recognition paradigm suggests that subjects may have truncated their usual processing of these problems in the recognition paradigm. Subjects apparently abandon their attempt to generate a solution internally, and instead search for the solution among the multiple choice answer alternatives provided.

Review of the Modified Processing Model

The Processing of Inclusiveness and Specificity

In this first experiment both inclusiveness and specificity have been found to influence the solution latencies of four word analogy problems. Inclusiveness and specificity effects have been demonstrated in each of the two paradigms of this experiment using whole-part and part-part analogies. In spite of these commonalities, there are significant differences in the way these distinctions are designed into the stimuli of this experiment, and in the way the processing of these two distinctions are described by my model. A few of these contrasts will be briefly reviewed here.

One fundamental difference between inclusiveness and specificity is that specificity distinguishes between analogy types whereas inclusiveness distinguishes between association types as well as between analogies made up of these types. That is, the difference between an inclusive analogy and a noninclusive analogy can be determined by illustrated in the association in one word pair of a problem. For example, the whole-part association formed by **hand : palm** is inclusive, and the part-part association formed by **hand : elbow** is noninclusive. In contrast, specificity cannot be evaluated in the association in either of these word pairs. For example, **hand : palm** must be matched with another word pair before it can be judged to belong to a specific analogy, as in the case of **hand : palm** as **foot : sole**, or a nonspecific analogy as in **hand : palm** as **face : ear**.

A second important difference between these distinctions is the way they affect the difficulty of an analogy problem. Specificity alters the difficulty of an analogy because it controls how narrow or wide the propositional fan containing the solution word will be. That is, fewer answer alternatives will be generated and considered for a specific analogy than for a nonspecific one. Using the examples above to illustrate, fewer alternative answers exist for the specific analogy above containing the solution word **sole** than for the nonspecific example solved by **ear**. In contrast, the inclusiveness of an analogy does not alter this factor. For example, the number of possible answer alternatives is essentially equal for the inclusive whole-part analogy **car : wheel** as **boat :** _____ and the noninclusive part-part analogy **bumper : wheels** as **hull :** _____ .

These two important differences between inclusiveness and specificity are also reflected in how they are processed according to my componential model. The simplest distinction regarding their processing is that inclusiveness affects processing early in the model (at the inference component), whereas specificity influences processing later (at the mapping component and beyond). This difference in the location of effects in the model is accompanied by a difference in the nature of these processing effects as well. In the case of inclusiveness, the model assumes that the inference component initially consists of an attempt to find many types of associations until one is confirmed in the word pair. The model is oriented toward inclusive types since it assumes that more direct associations will be investigated first. Failing to find such associations forces the system to make extra inferential steps between the word pair: a process which increases the amount of deliberate, cognitive effort involved in this component, and increases the overall solution latency for the analogy problem. In the case of specificity however, the model is oriented toward the more difficult, nonspecific types since application and justification components are only of consequence if the analogy is nonspecific. The use of these components is required for nonspecific analogies because for these analogy types the mapping of attributes from first to third words is incomplete, and leads to the generation of multiple answer alternatives. In contrast, the processing of a specific analogy alters the execution of these processing components because the details of the association activated at the inference component are transferred efficiently at the application and justification components. The efficiency of this procedure essentially eliminates the need for processing in these components of the model.

These differences between inclusiveness and specificity are based on observations of the stimuli, and speculations about the nature of their processing mechanisms. Although the preceding discussion is meant to present the case that inclusiveness and specificity may be orthogonal dimensions, it is acknowledged here that no conclusions about the relationship between these two dimensions can be made without a more direct investigation of this question.

Processing Differences Between the Paradigms

The comparison of latencies from the recall and recognition paradigms failed to support my speculation that the recall paradigm would produce longer latencies because it requires subjects to generate a spoken response. However, the second predicted processing difference between paradigms does seem evident in the results of this experiment.

I believe the interaction of both specificity and inclusiveness with these paradigms indicates that two justification components are required in the model, and that they are used to moderate the latencies of very difficult problems in the recognition paradigm. The internal justification component is proposed as an automatically first tried process for choosing an answer to a problem. In the recall paradigm, since no externally provided alternatives exist, this is the only type of justification component at work. In the recognition paradigm however, when this internal justification process becomes very time consuming (i.e. for difficult noninclusive and/or nonspecific problems) the subject may deliberately defer to an external justification process as a time saving technique. How would this strategy of resorting to external justification increase the processing efficiency of nonspecific and noninclusive problems?

In the case of nonspecific problems, because the set of potential answer alternatives is not constrained as narrowly as it is for more specific ones, subjects are more apt to become overburdened by the demands of the internal justification task, and are therefore likely to seek an alternative strategy. Furthermore, since these nonspecific problems are so time consuming to solve, subjects have more processing time to save by resorting to an external justification process when solving these problems.

In the case of noninclusive analogies a different reason for resorting to external justification is required. This is because, as explained above, an inclusive analogy such as **car : wheels** as **boat :** _____ taps essentially the same set of potential answers as an noninclusive analogy referring to the same subject matter, such as **bumper : wheels** as **hull :** _____ . However, because this is only true after the subject has inferred the subject matter of the second word pair, there is still reason to believe that subjects more often become overburdened by the processing demands of noninclusive problems than inclusive problems. The difficulty of noninclusive problems arises from the task of determining the identity of the whole referents in part-part analogies, and the superordinate categories in same class analogies.

To understand how difficult this task may be, consider how subjects might decide on the solution to a noninclusive analogy such as **branch : root** as **leg :** ____ . Subjects presented with this example know: i) that a whole object must be inferred, and ii) that one of the parts of this object is **leg**. The identity of this whole object is not entirely obvious because **leg** may be interpreted as part of **table, chair, human, trousers,** as well as **animal**. This contrasts with the processing of inclusive whole-part analogies, such as **tree : root** as **animal :** _____ which provide subjects with the whole word referent (eg. **animal**) and thereby directs the nature of the part required as a solution.

Thus, for noninclusive analogies subjects may process many interpretations concerning the identity of the inferred whole object (or superordinate class), and spend a significant amount of time choosing from among them, or choosing from among the sets of solution alternatives generated from each of them. In this way, subjects may resort to an external justification component to expedite the extra processing created by the extra inferential step involved in noninclusive analogies.

In summary, the solution latencies yielded by the two paradigms did not confirm the speculation of an additional time-consuming process in the recall paradigm. However, I believe that the pattern of latencies from the two paradigms, across analogy types, does support the existence of two different justification components in my model. I believe the presence of multiple choice answer alternatives in the recognition paradigm allows subjects to circumvent some of the processing demands of nonspecific and noninclusive problems in that paradigm by resorting to an external justification process.

Chapter Summary

The present experiment has shown that different analogy types produce different latencies according to the inclusiveness and specificity hypotheses proposed in this chapter. Furthermore, these systematic differences are consistent across the two paradigms, and among the problems within each analogy type. The different response paradigms did not produce consistently different solution latencies. While the latency differences existing between the two paradigms supports the processing model proposed, the lack of an overall main effect of paradigms suggests that the processes used by subjects performing in these two paradigms consume comparable amounts of time.

In general then, these results confirm the hypotheses regarding differences among analogy types, and affirm these paradigms as useful experimental vehicles. These demonstrations allow this thesis to turn its focus toward experiments designed to explain why these differences exist. The pursuit of this goal will begin in the next experiment, which attempts to prime analogies by their type, in an attempt to study the role of the inference component in solution generation.

CHAPTER SIX
EXPERIMENT 2: PRIMING OF ASSOCIATION TYPES

Overview

This experiment examined whether subjects would solve analogy problems faster if they were primed with the association type. In this way, this experiment tested whether analogy problems of a common type involve a similar cognitive procedure. Experiment 2 was conducted using both the recognition paradigm (Experiment 2A) and the free recall paradigm (Experiment 2B). The rationale and method are presented first. The results show some evidence of priming and provide a close replication of many findings from Experiment 1. The discussion offers an explanation of the results of priming and proposes further experimentation to explore the cognitive processes involved.

Rationale

The 80 analogy problems from Experiment 1 were presented in blocks according to analogy type. By this method, a subject saw a sequence of ten part-part problems, for example, followed by the ten problems of another analogy type. This method allowed subjects to use information from the first few problems in a block to solve the subsequent problems in that same block. Because it was hypothesized that analogy problems with the same defining characteristic necessarily share a common part of the cognitive procedures used to solve them, priming was expected to save subjects the time required to perform this part of the procedure, when solving problems late in the block. This was expected to result in shorter solution latencies for these problems. Another possible outcome of this experiment was that the blocked presentation would not affect latencies. This result could occur if problems within a block do not present subjects with a common core of processing demands, or if these common demands consume relatively little time in the total solution process.

This experiment also examined how the priming manipulation affected the solutions of the different types of analogies. It was expected that priming would have a larger effect on analogy types that consumed a great deal of processing time at the inference component, where the initial representation of the first association in the analogy is formed. This processing includes activating word attributes and drawing inferences between these words to create the relevant association. If these processes are successfully primed in this experiment, then the priming effect should be proportionately greater for analogy types that are time consuming to process at this inference component. Noninclusive types, and analogy types at the higher tiers of the functional/structural dimension fit this description; the former because their noninclusive associations require extra inferences to form, and the latter because their associations are usually accessed more slowly than those at the lower tiers. Accordingly, the general priming hypothesis for this experiment states that the latencies of different analogy types should show latency reductions from priming in proportion to the length of their original latencies in Experiment 1.

Hypothesis 2.1: Priming will reduce latency scores in each analogy type in proportion to the latency of their solution in Experiment 1.

Method

The method of this experiment differed from the general method in a few important ways. Instructions informed subjects that there were eight different types of analogy problems, that they would see ten examples of each, and that these ten examples would be presented consecutively. The presentation of analogies began with a message on the computer screen which stated "You are now starting a new block of analogies using a different type of pattern". The ten problems of a particular type were then presented in a random order. This new-block message re-appeared to introduce each subsequent block.

The order of the problems within blocks, and the order of blocks, was randomized differently for each subject. Both Experiment 2A (recognition paradigm) and Experiment 2B (free recall paradigm) occurred this way. All other aspects of the method were repeated in these experiments as they occurred in Experiments 1A and 1B, respectively. Subjects were 12 male and 12 female undergraduate students selected from the same population used in the Pilot Studies and described in Chapter Four.

Results

Evaluating the Priming Effect

The latency data from this experiment were scored the same way as for the subjects analysis of Experiment 1. Response latencies were used to compute each subject's median score on the ten problems of each analogy type. The means of these medians across all subjects are plotted together with the results of Experiment 1 in Figures 10 and 11, for the recognition paradigm, and the free recall paradigm, respectively. Table 9 lists these mean latencies for both paradigms in both experiments.

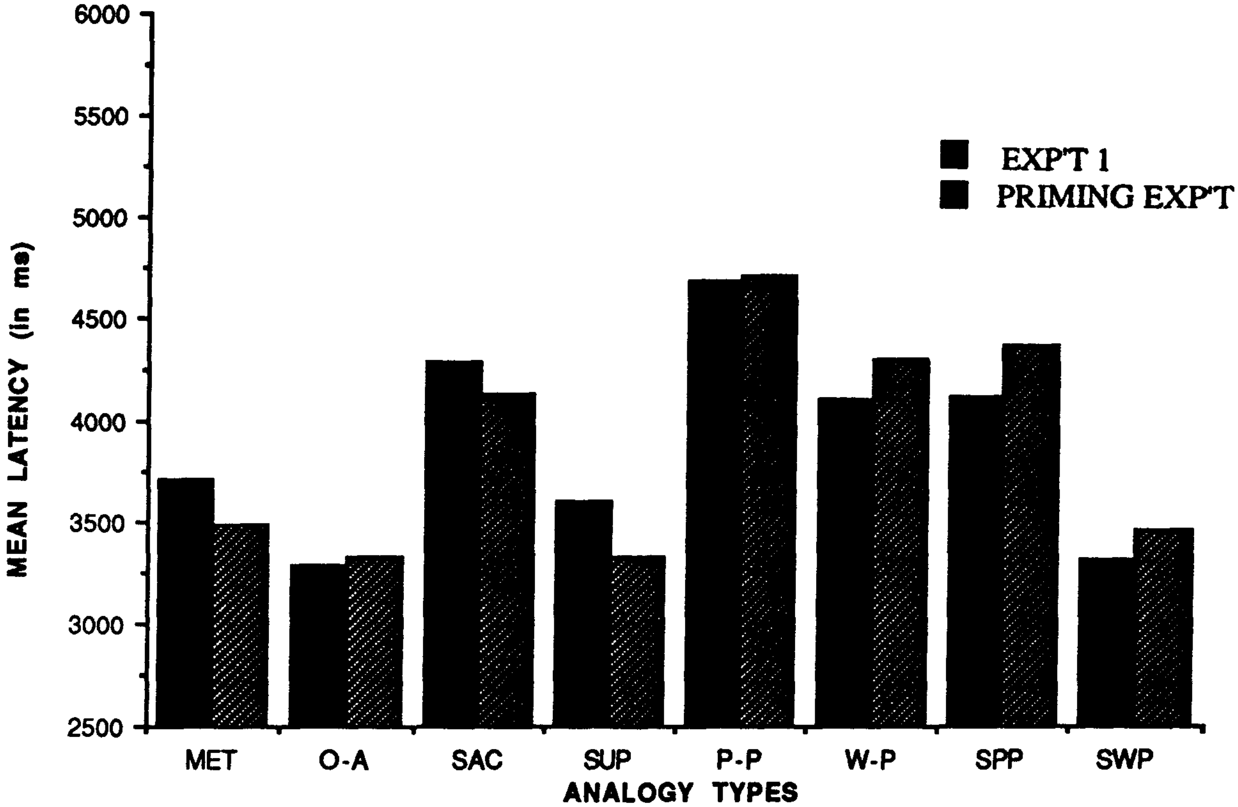
These figures reveal that presenting analogies in blocks according to their type did not produce a consistent priming effect. In the free recall paradigm (Figure 11), subjects were quicker at solving problems of all eight analogy types when they were presented in blocks, but for most types the overall time savings was not large. In the recognition paradigm (Figure 10), only

Table 9

Mean Solution Latencies From Subjects Analysis in Experiment 1
and the Priming Experiment

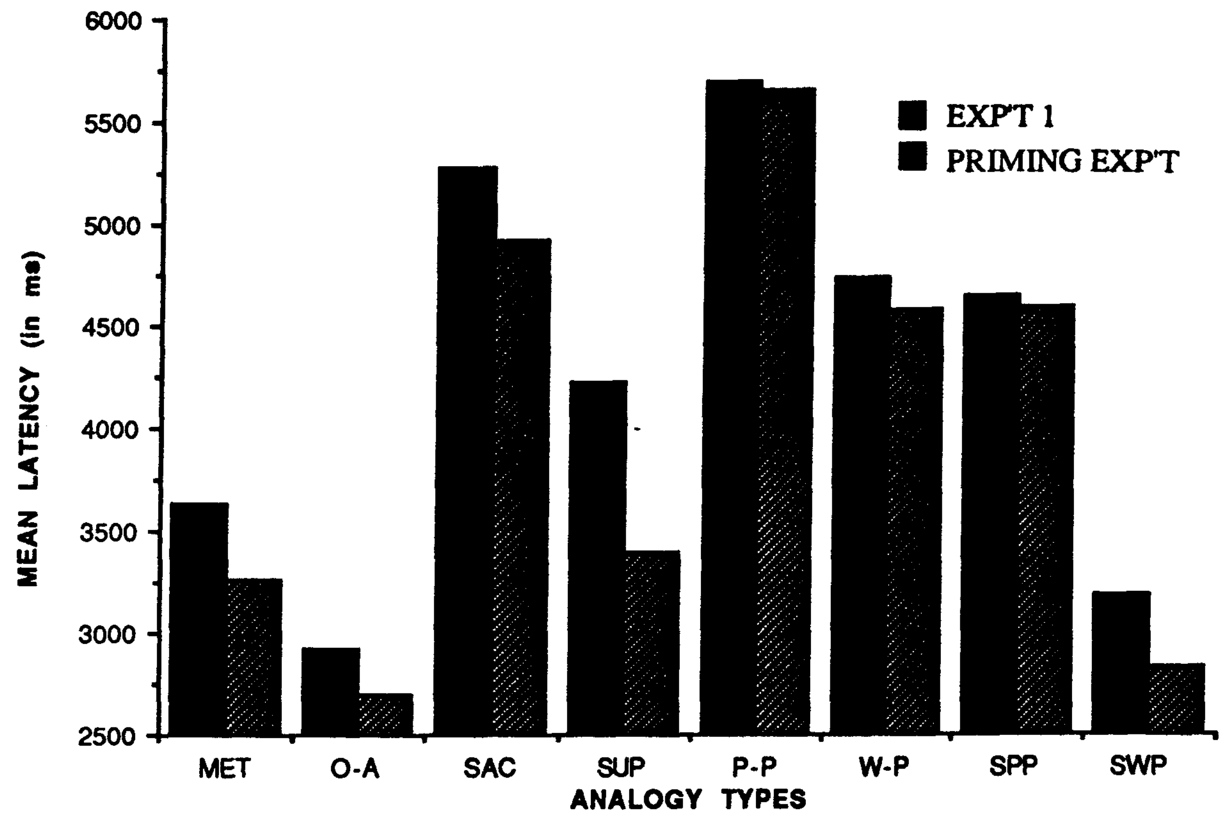
Experiment	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
1A (recognition):	3717(185)	4291(290)	4686(312)	4115(224)
2A (recognition):	3481(177)	4131(338)	4708(314)	4364(260)
1B (recall):	3630(238)	5279(326)	5695(372)	4646(283)
2B (recall):	3266(165)	4918(337)	5654(387)	4592(282)
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
1A (recognition):	3286(119)	3603(171)	4109(242)	3316(159)
2A (recognition):	3325(211)	3333(189)	4305(264)	3454(153)
1B (recall):	2919(151)	4225(342)	4736(347)	3179(190)
2B (recall):	2693(126)	3392(224)	4580(269)	2825(125)

notes. latencies are given in milliseconds.
standard error values are bracketed.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 10. Mean solution latencies from subjects analysis of recognition data from Experiment 1 and the Priming Experiment.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 11. Mean solution latencies from subjects analysis of recall data from Experiment 1 and the Priming Experiment.

metamorphosis, same class and super/subordinate analogies showed any evidence of priming.

Experiment 1 has shown that analogy types distinguished by specificity, inclusiveness or the functional/structural dimension yield solution latencies that indicate they are of different levels of difficulty. Since Hypothesis 2.1 concerns the effect of priming on analogies of different levels of difficulty, this hypothesis was tested by comparing the data for Experiments 1 and 2 on each of these dimensions. This analysis took the form of a series of ANOVA designed the same way as in Experiment 1, with the additional factor of experiment type (Experiment 1 vs. 2). Two mixed design 2 X 2 X 2 ANOVA were performed comparing the analogy types on the top tier of the cube in Figure 1, between Experiments 1 and 2. The two analyses addressed these comparisons separately for the recognition and free recall data. As in the results for Experiment 1, an alpha level of .05 can be assumed for statistically significant results reported in this chapter. The sources tables for these ANOVAs and all others reported in this thesis appear in Appendix Z.

In both analyses, there was no main effect of priming (i.e. between Experiments 1 and 2), and there were no significant interactions of this factor with either specificity or inclusiveness (all $\underline{F}$ values < 1.1). A main effect was found for specificity, $\underline{F}(1,46) = 52.2$, $\underline{MS}_e = 376136.3$, and $\underline{F}(1,46) = 84.6$, $\underline{MS}_e = 1023888.7$, for recognition and recall data respectively. These analyses both found a main effect of inclusiveness as well, $\underline{F}(1,46) = 49.9$, $\underline{MS}_e = 434437.6$, and $\underline{F}(1,46) = 66.7$, $\underline{MS}_e = 1249335$, respectively.

In order to test the effect of priming on inclusiveness across the three levels of the functional/structural dimension, and to test the effect of priming across the three levels of this dimension, a pair of 2 X 2 X 3 ANOVA were run, one for the data of each paradigm. In both analyses no effect of priming was discovered, (all $\underline{F}$ values < 1), and priming did not interact with either inclusiveness or the structural/functional dimension (all F values less than 2).

The failure to find priming in the analysis described above is perhaps not surprising for the following reason. It was expected that subjects presented with blocks of problems would use the first few problems to discover the nature of the association appearing in the block, and would use this information to solve the remaining problems. By this view, priming should only reduce latencies for problems presented toward the end of each block. To examine this possibility, the response latencies for the ten problems of each type were plotted according to their serial position. The median latencies across all 24 subjects make up the data points for these plots, which appear in Figure 12. A separate plot is presented for each analogy type in both recognition and recall paradigms.

For several analogy types, Figure 12 shows a progressive reduction in latencies across the block of ten problems. The analogy types showing best evidence of this priming are, in decreasing order: same class, part-part, metamorphosis, and super/subordinate analogies. The remaining four types showed no such trend: whole-part, specific whole-part, specific part-part and object-action. Figure 12 presents the eight serial position plots representing each of the different analogy types in the order listed above, starting with analogy types showing the most evidence of priming. These serial position plots appear to be a more sensitive portrayal of the effects of priming across analogy types than the earlier analysis of mean latencies. The findings of this analysis are confirmed by the fact that analogy types showing priming in their serial position patterns are the same types that show the most reduced mean latencies in Figures 10 and 11. Although these effects are modest, priming is evident in the three noninclusive, nonspecific types (same class, part-part and metamorphosis), and in the super/subordinate analogies.

Evaluation of Data as a Replication of Experiment 1

Since the effects of this priming manipulation were not large in magnitude,

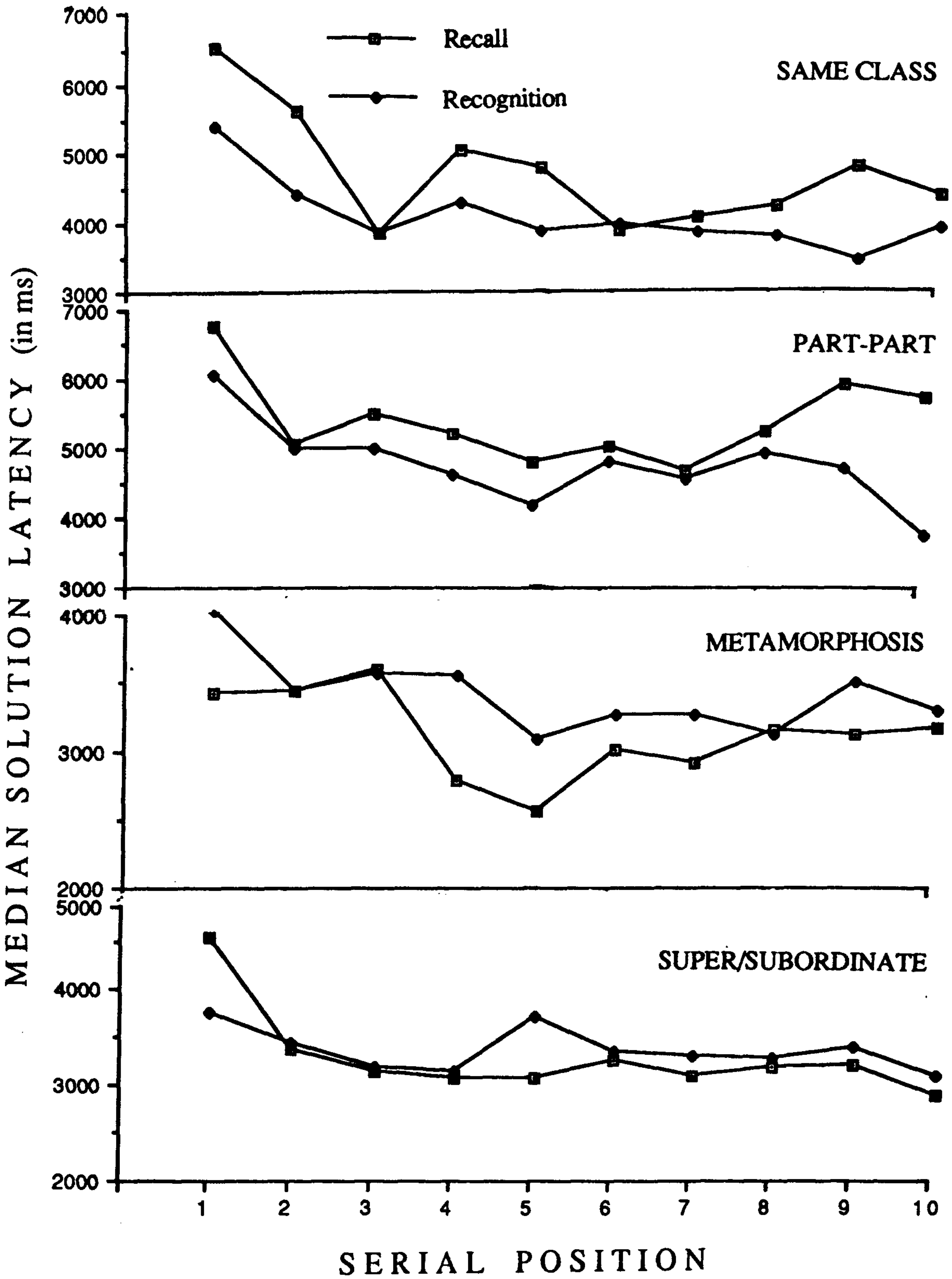


Figure 12. Serial position curves of recognition and recall data for each analogy type in the Priming Experiment.

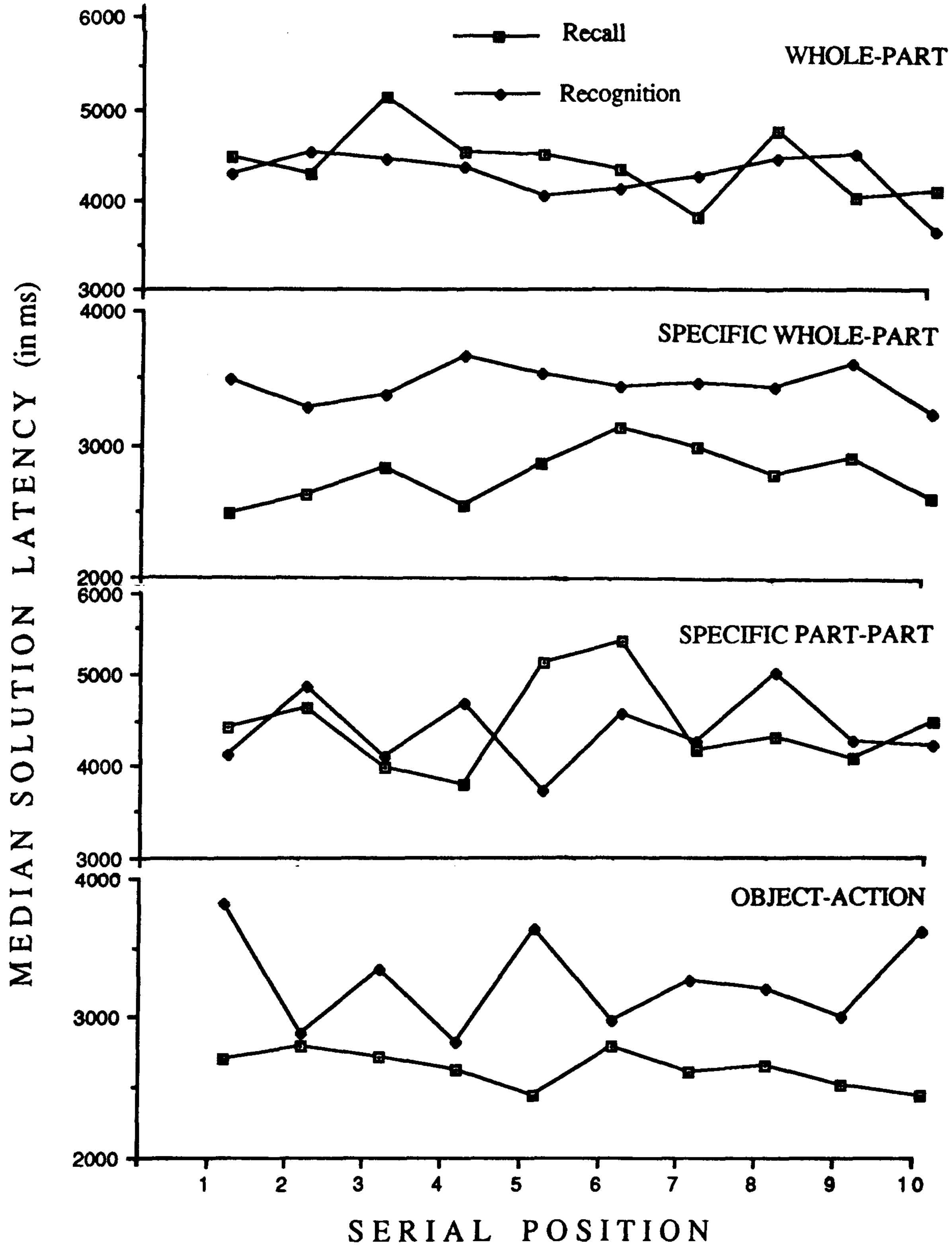


Figure 12. Serial position curves of recognition and recall data for each analogy type in the Priming Experiment (continued).

the pattern of solution latencies across analogy types was similar in this experiment to that of Experiment 1. To directly test whether this experiment replicated the results of Experiment 1, the same series of statistical analyses used to test the hypotheses of Experiment 1 were conducted on the data of this experiment. The results of these analyses will be summarized here; details appear in Appendix H.

Differences Among Analogy Types

As in Experiment 1, a pair of 2 X 2 ANOVAs were performed on the four critical analogy types at the top tier of the typology cube in Figure 1. In the data of both paradigms both main effects of inclusiveness and specificity were confirmed. Unlike the results of Experiment 1, however, an interaction between these main effects appeared in the recognition data, indicating that the specificity effect was not as large for the part-part types as it was for the whole-part types.

As in Experiment 1, the consistency of latencies for the ten problems of each type was tested through an alternate items analysis. As well, subjects' responses in the recall paradigm were scored by alternate judges. As was the case in Experiment 1 these analyses showed mean latency values very similar to those of the original subjects analysis reported above. Details of the results of these analyses appear in Appendix I for the data from the recognition paradigm, and Appendix J for the recall paradigm.

As in Experiment 1, a pair of 2 X 3 repeated measures ANOVA were performed on the six analogy types forming the front face of the cube in Figure 1, to test the effects of inclusiveness and the functional/structural dimension among these six analogy types. In both paradigms both main effects were again significant, as was the interaction between them.

The results of Newman-Keuls multiple comparisons performed on the data from each paradigm are presented in Appendix K. In the recall data this analysis again confirmed specificity, inclusiveness and functional/structural hypotheses in most comparisons. The only exceptions were a nonsignificant difference between object-action and metamorphosis types on the inclusiveness dimension, and a nonsignificant difference between object-action and super/subordinate types on the functional/structural dimension. In the recognition data this analysis showed a pattern of results identical to that of the recall data with one significant exception: all three comparisons involving the part-part type were nonsignificant. This created a nonsignificant difference between analogy pairs on each dimension of the typology cube. These results occurred because the latencies for part-part analogies were not long enough to distinguish them from whole-part, specific part-part or same class types. In light of this, and since these part-part problems were among the most successfully primed in this experiment, I believe these insignificant differences resulted from the priming of part-part analogies, and therefore do not discredit the hypotheses concerning these analogy dimensions.

Comparing Paradigms

Statistical analyses comparing the results from the recognition and recall data of Experiment 2 confirmed much of the findings from Experiment 1. (Appendix K compares these data graphically.) Among the top tier analogy types no main effect of paradigms was found, but the latencies of the two paradigms interacted with both specificity and inclusiveness. Both of these interactions were like those of Experiment 1; the specificity effect was enhanced in the recall data relative to the recognition data, and the difference in solution latencies between noninclusive part-part analogies and inclusive whole-part analogies was greater in the recall paradigm than in the recognition paradigm. The analysis of the six analogy types on the front face of the typology cube also yielded familiar results; no main effect of paradigms was found, but this factor did interact with both inclusiveness and the functional/structural dimension.

<u>Errors</u>

In this experiment error rates in the recognition paradigm (less than 1%) and the free recall paradigm (7.1%) were lower than in Experiment 1, by 1% and 4%, respectively. (See Appendix K for error rates by each analogy type.) As in Experiment 1, the pattern of the errors across analogy types replicated many of the results found in the latency data, since analogy types with longer latencies tended to also produce greater error rates ($r = .77$ for recall data). This relationship was also evident in specificity and inclusiveness effects among the error rates. If the error rates of Experiments 2A and 2B are combined, specific part-part and whole-part analogies yield a total of 30 errors compared to 65 errors for the nonspecific types. Inclusive analogies accounted for 36 errors, while the noninclusive analogies accounted for 119. Chi square analyses confirmed each of these distributions as significantly unequal ($\underline{p} < .01$).

<u>Exceptional Analogy Problems</u>

This final analysis examined the solution latencies found in this experiment in order to determine whether any analogy problems were consistently exceptional in Experiments 1 and 2. Both outliers and inconsistent problems were identified and studied by methods identical to those used in Experiment 1. To discover outliers, all problems whose median response times across the 24 subjects was more than 1.5 standard deviations away from the mean for that analogy type (i.e. $Z < -1.5$, or $1.5 < Z$) in the data from both paradigms were identified. Only one problem (**plaster : crack** as **stocking : run**) fit this pattern, as it elicited consistently long latencies in the two paradigms. This problem was not an outlier in Experiment 1.

Inconsistent problems were discovered by comparing the standard deviations (Z-scores) of the latencies for each analogy in the two paradigms. If a problem's solution latency relative to others in its type differed greatly between recognition and recall paradigms (i.e. by more than 2 Z), it was identified as an inconsistently solved problem. Seven such problems were found, from four different analogy types. These problems, their latency differences in the data from the two paradigms, and the analogy type they represent are presented in Appendix L. None of these inconsistent problems were also identified as such in Experiment 1.

Discussion

The manipulation performed in this experiment did not demonstrate a consistent priming effect. This manipulation neither reduced latencies equally across analogy types, nor did it affect analogy types in proportion to their solution latency in Experiment 1. Thus, Hypothesis 2.1 proposed at the outset of this chapter was not confirmed.

The following discussion of this finding has two sections. In the first, the limited success of priming for some analogy types in this experiment will be reviewed briefly in order to discount a possible confound in these results. The second section presents a discussion of the cognitive processes I believe are involved in priming, in order to describe some possible reasons why this priming manipulation did not produce a more pronounced effect.

The Case Against Practice Effects

The analysis of serial position data in this experiment raises an important question regrarding the nature of the effect discovered. This question concerns the nature of the information producing this effect and how long lasting this priming benefit might last. The information received by subjects in this experiment might constitute an enduring change in subjects abilities generally, or it might constitute a short-term priming effect only on immediately subsequent items. I wil refer to the former as a practice effect and the latter as priming.

This question can be addressed by comparing the results of this experiment with those of Experiment 1. If the processing advantage for analogy problems in Experiment 2 is an enduring practice effect, then similar effects should appear in the data of Experiment 1 where the same problems of each analogy type were presented to subjects over a longer period of time (i.e. throughout the course of the 80 problems). That is, if the decrement of latencies across serial positions evident in Experiment 2 also appears in the serial positions of problems in Experiment 1, the effect in Experiment 1 must be due to practice, and this explanation is equally valid for the results of the present experiment.

Figure 13 displays the serial position curves for the data of Experiment 1. In these figures the ten problems of each analogy type form a sequence of ten serial positions according to the order of their occurrence within the complete block of 80 analogies. Thus, every subject yields a serial position curve for each analogy type, each consisting of ten serial positions. In the summary data comprising the curves in Figure 13, each serial position data point represents the median latency value for that serial position, across the 24 subjects. Since no pattern of reduced latencies over time is evident in any of the serial position curves for Experiment 1, it must be concluded that the data patterns evident in Experiment 2 were due to short-term priming, not a more enduring practice effect.

Implications of Priming Failures and Successes

The failure of the present experiment to produce consistent priming effects indicates that the information presented to subjects about the association types did not enable them to solve subsequent problems of the same type more quickly. This was surprising because it was expected that defining characteristics would play a major role in the inference process, and that if it were primed, significant latency savings would result. In this discussion I argue

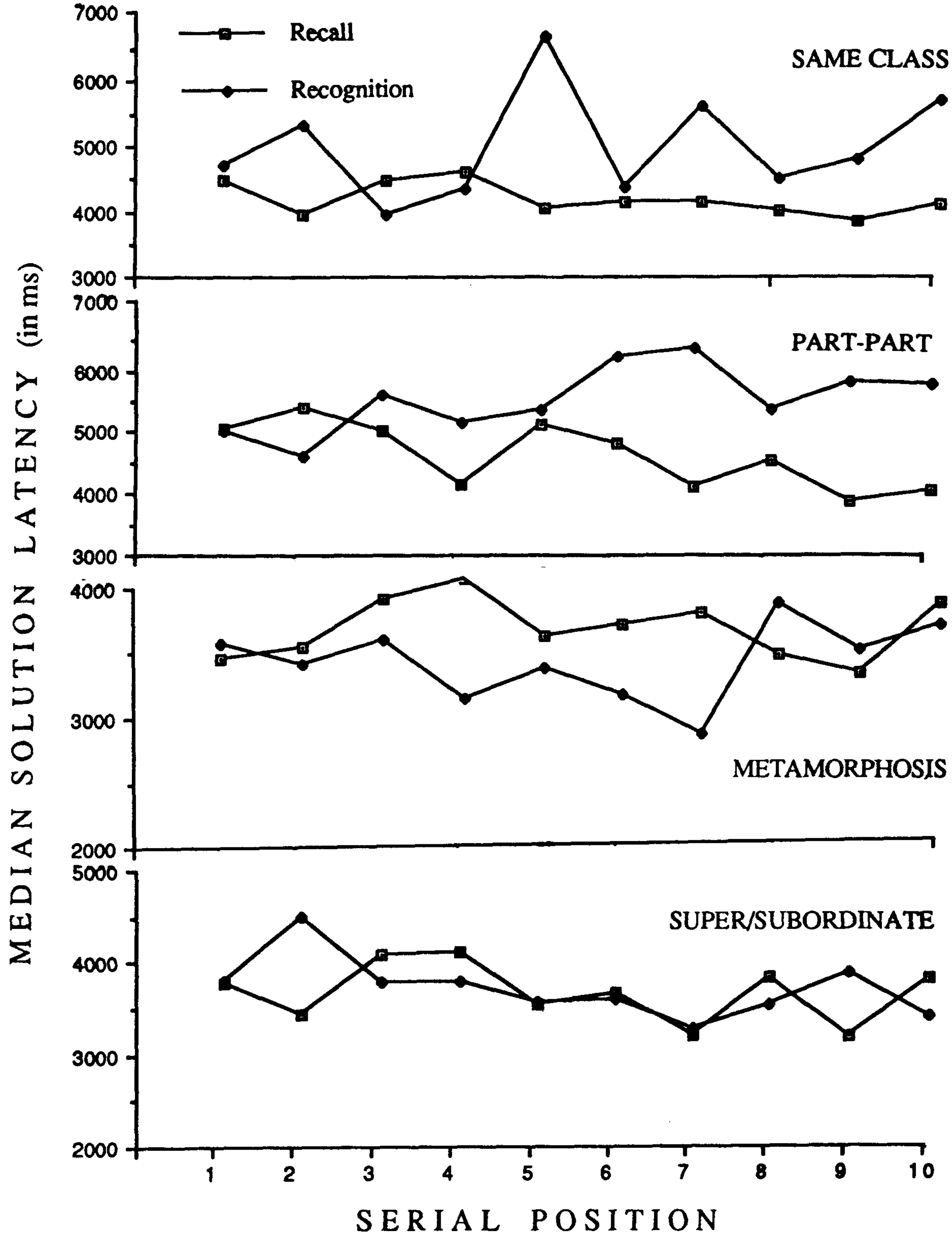


Figure 13. Serial position curves of recognition and recall data for each analogy type in Experiment 1.

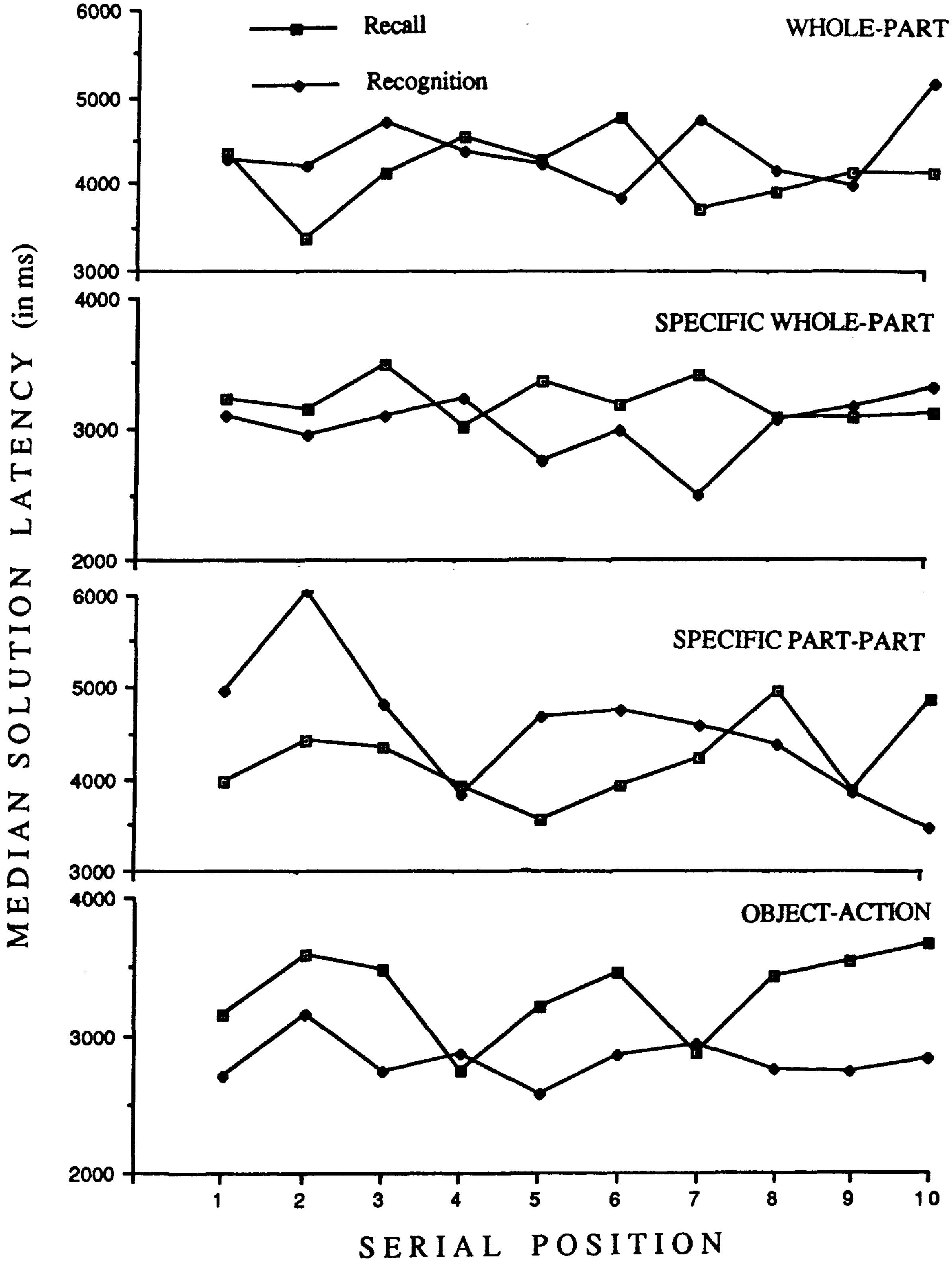


Figure 13. Serial position curves of recognition and recall data for each analogy type in Experiment 1 (continued).

that, despite the rather minor priming effect found in this experiment, this hypothesized role of the defining association characteristic in the inference component cannot be conclusively ruled out on the basis of this experiment.

I believe that the relative failure of the priming manipulation performed in this experiment may reflect the procedural nature of processing at the inference component. I have described this process as one whereby the cognitive system processes much information about the first word pair including many specific attributes of the words themselves, as well as the defining characteristic of the association. As a result of the tendency of the cognitive system to process associations at this detailed level, subjects attention to information about the common association type in a series of problems may become distracted by the idiosyncratic detail present in each problem. That is, the weak priming effects demonstrated in this experiment may reflect the failure of subjects to receive the information about the defining characteristic of the association, rather than its insignificant role in the processing of the inference component.

The following discussion expands this explanation in three sections. The first will elaborate how the processing activity of the inference component might have left the subject unable to recognize the information about association types as it was presented in this experiment. In the second section the nature of the information that was successfully primed in this experiment is reviewed and accounted for by the processing of the inference component. In the final section future research is proposed to further test this explanation.

Reasons for Priming Failure

The explanation I wish to promote for the results of this experiment is based on the possibility that the usual activity of the inference component does not necessarily form an explicit representation of the defining characteristic of the association found between a word pair. That is, the entire representation of the association in a problem involves the activation of so many other associations and attributes that this defining characteristic may not receive sufficient attention to be remembered from one analogy problem to the next. Such a scenario accounts for the modest priming effects of this experiment without disclaiming an important role for the association type in this process.

To illustrate how this process might occur, consider the processing demands that subjects face in attempting to find the solution to a problem such as **restaurant : kitchen** as **school : _______** . Early in the act of solving this problem, at the inference component, the association between the first and second words is necessarily represented as a large set of characteristics. This is because the subset of these characteristics that will be relevant to the solution in the second word pair cannot be known until mapping begins. So, for example, the representation of the association in **restaurant : kitchen** might initially include a reference to the productive nature of kitchen, its heat, the equipment contained in it, as well as the general fact that a kitchen is part of a restaurant. Although processing the third word (in this example **school**) should help narrow this set of characteristics as the system discovers which are relevant to the third word, much information may remain relevant, even at this point. To illustrate, the subject may choose the equipment characteristic as a basis for the association and respond with the solution word **gym**, or the heat characteristic (as in the solution **boiler room**), or the production characteristic (as in **classroom**).

Thus far, two points have been illustrated here. One is that after solving one analogy problem the complexity of the particular words contained within it may have consumed a large amount of processing resources. The second is that even after this first problem has been solved, the information used to represent the association may include other characteristics in addition to the defining characteristic of the association (in this case, whole-part).

As this illustration has shown, it is likely that information from more than one problem is required before the association type can be known by the subject. However, even at this point the rich set of attributes contained by the particular words used may leave the nature of this association unresolved. For example, subjects presented with the analogy **apple : seed** as **cabbage :** ______ immediately after the restaurant example might find a common food theme in the words of the two problems. In short, if the processing system is predisposed to use details about the words contained in problems, the nature of these words may obstruct the discovery of the association's defining characteristic.

A second factor compounding the difficulty of realizing the nature of the association type is that subjects were not given any explicit instructions to do so. Subjects in Experiment 2 were merely told that the ten problems in a block shared a common association type, and that this fact might help them solve the problems quickly. Whether these instructions motivated subjects to identify the common association type in a block is uncertain, but these instructions certainly encouraged subjects to direct their efforts to solving the problems quickly. This encouragement may have discouraged subjects from attending to the information about the common association type between problems.

Work by Gick and Holyoak (1983) provides support both for the suggestion that subjects must encounter multiple examples of a problem type before they can form a general representation of its essential characteristics, and for the speculation that experimental instructions may influence subjects' success at this task. Their work used variations of the General problem, the Radiation problem, and a similarly structured problem with a fire-fighting theme called the Fire Chief. These authors attempted to help subjects recognize the relevance of the General problem and/or the Fire Chief problem when they were presented as vehicle problems, in order to solve the Radiation problem which was presented as the target. Results showed that presenting subjects with one vehicle was largely ineffective in cuing them to transfer the vehicle's structure to solve the target problem. However, in conditions where subjects were provided with the two vehicle problems of a similar form or *schema*, performance on the subsequent target problem was enhanced. Gick and Holyoak postulated that when subjects had only one problem to access they were unable to extract the schema of the problem from the details of the actual objects contained in it. However, when two problems were presented, subjects were better able to recognize the relevant information in common between the two problems.

In a subsequent manipulation, these authors (Gick & Holyoak, 1983) attempted to further improve the problem solving abilities of their subjects by presenting cues regarding the nature of the story structure contained in the vehicle(s). In one condition, these cues took the form of explicit instructions for the subject to form summary statements about the structure of the problem(s) presented. In another condition subjects were provided with a summary statement designed to draw their attention to the structure. In the General problem this statement consisted of the following:

> The general attributed his success to an important principle: If you need a large force to accomplish some purpose, but are prevented from applying such a force directly, many smaller forces applied simultaneously from different directions may work just as well (Gick & Holyoak, 1983, p. 16).

Results showed that when only one vehicle was provided, these cues had little effect on performance, but when two vehicle stories were provided they increased the likelihood of the subject transferring the solution. So, if subjects are given an opportunity to extract the solution structure from the details of two similar problems, additional explicit cues produce additional benefits in task performance.

I believe this work is relevant to the results of the present experiment because, like Holyoak's subjects, subjects in this priming experiment had difficulty forming a general representation of the defining characteristics of the problem type because they were faced with a great amount of other detail in solving each problem. The relevance of this work was unexpected at the outset of this experiment, however. It was thought that Holyoak's subjects encountered this difficulty because the stimuli used in these experiments consisted of full stories from different subject areas, each containing a great deal of detail irrelevant to the common schema existing between them. My four word analogies were thought to be less complex since only the words containing the associations themselves are presented to subjects. The hypothesis I now propose states that significantly distracting details do exist in the form of multiple attributes in each of the words contained in the problems. Future experiments may determine the viability of this hypothesis. If, as in Holyoak's experiment, experimental instructions can be altered to help subjects overcome the effects of this distracting detail, then the role of the defining characteristics of association types will be confirmed. Some specific experimental proposals to realize this effect are presented in the final section of this discussion.

Information About Associations Successfully Primed

The results of Experiment 2 suggest that two types of information were primed in this experiment. One of these is information regarding the nature of noninclusive associations, since three of the four analogy types showing priming were noninclusive. The other information successfully primed appears to have been a representation of the super/subordinate association type, since these analogies also showed priming.

Noninclusive, nonspecific analogy problems are relatively difficult to solve, particularly because they require the subject to infer a mediating concept to form the association between word pairs. The first few problems in a block of noninclusive problems probably demand a significant amount of deliberate cognitive effort when forming these associations in the inference component. This deliberate effort may be responsible for providing subjects with a representation of this association characteristic (inclusiveness) that is sufficiently salient to be remembered between problems and to become accessed at the inference component of subsequent problems in the block.

The priming of super/subordinate problems requires a somewhat different explanation because they are inclusive, and because the results of Experiment 1 indicate that this analogy type is not a particularly difficult one. In this case the salience of the association type may be due to the fact that it is easily represented by a verbal code, such as "(corn) is a type of (vegetable)". Both the form of this representation and its ready use may result from the great familiarity subjects have using this association. Evidence of this familiarity comes, for example, from the great emphasis that the North American educational system places on taxonomic categories of living things and other objects. While this explanation is highly speculative, it was supported by anecdotal comments collected from subjects in this experiment. Some subjects who reported that the blocked presentation helped them solve some problems illustrated this claim using the super/subordinate analogy type as an example, reciting phrases such as "(corn) is a type of (vegetable)".

Thus, the priming produced in this experiment probably resulted from the relative salience of the information about the association types involved. In this way future priming studies which make the appropriate information salient to subjects may yet demonstrate that the association type in a problem has a significant role in the processing of analogy problems.

Future Research

Given the previous assertions that the failure of priming in this experiment occurred because the information about association types wasn't sufficiently salient to subjects, questions remain as to how this information could be presented in an effective form, and how much cognitive processing time would be primed if this occurred.

One hypothesis regarding this issue is the possibility that, while subjects under ordinary circumstances would learn the relevant information about association types and use it to prime solutions to subsequent problems, they were prevented from doing so in this experiment due to time restrictions. This hypothesis can be tested by simply presenting the same analogy problems used in Experiment 2 under conditions where subjects have more time to reflect on the common association type among them. If this time resource was a disabling constraint, then priming should be enhanced by allowing subjects to view these problems after they have completed them, until they indicate they are ready to see the next problem.

A second related explanation of the modest priming found in this experiment is that subjects' cognitive resources were overburdened by the rich set of attributes contained in the words of these problems. That is, these word attributes consumed so much of the subjects' attention that subjects were distracted from realizing the common association characteristics between problems. In fact, the present experiment was designed in such a way that the diversity of these word attributes was very large, since an explicit attempt was made to vary the subject matter among the ten problems in each block. For example, the part-part type includes problems referring to mechanical objects (eg. car), buildings (eg school), social groups (eg, team) and collections of objects (eg. table place setting). Assuming that this diversity contributes to the cognitive load that subjects experienced, a less taxing condition could be designed by constructing a block of ten analogy problems using similar subject matter. For example, an entire block of whole-part problems could refer to mechanical objects, or a whole block of object-action problems could refer to animals. If the hypothesis proposed here is valid, then priming should be enhanced by this reduction in the diversity of the words used across problems.

If these attempts to reduce the cognitive demands of the task do not result in subjects acquiring the necessary information to produce priming, then a third question arises as to whether subjects' ability to quickly solve problems would be enhanced if this information was explicitly presented to subjects. This information might be presented in the form of instructions for subjects to construct their own representation of the association type (as Gick and Holyoak did), or as verbal code providing subjects with an explicit representation of the relevant association. The latter might take the form of association labels such as "whole-part" presented prior to a block of analogies, or mnemonic phrases such as "part of a (boat) is a (mast)". In contrast to the earlier two proposals, this experiment would determine whether explicitly provided representations of associations would produce a processing benefit, rather than manipulating features of the problems themselves in order to illustrate subjects' abilities to extract this information. Thus, this strategy would constitute the most direct test of whether association types have a significant role in solving analogy problems.

Finally, another research strategy for studying the role of association types in the process of solving analogy problems is to determine what information has been primed by eliciting subjects' explicit reports, and comparing this information to its relative effect on subjects' solution latencies. Gick and Holyoak (1983) recognized this strategy, and provide a precedent for studying the effect of subjects' explicit learning on problem solving performance. In a condition of their study where subjects were provided with two vehicle problems and with cues designed to direct their attention to the common structure of these problems, Gick and Holyoak had their subjects describe the their representation of these problems' structure. They then compared each subject's description to that subject's solution performance, and found that subjects who were able to summarize this solution structure accurately were more likely to have solved the target problem. In the present research, investigating this relationship between the nature of the information represented and its effect on solution latencies could determine the relative importance of the association type in the solution process. For example, the present experiment showed modest levels of priming for the part-part analogy type. Subjects' descriptions about the nature of the similarity among these problems would indicate whether this level of priming resulted from their awareness of the association type per se, or whether subjects had learned only that the association formed an indirect link between the two words (i.e. noninclusiveness). If the latter is confirmed, subsequent experiments such as those proposed above might find that a different level of priming when subjects form a more exact representation of the association type. Ultimately, this type of analysis between experiments could potentially provide a clear picture of the relative role of association types and other semantic characteristics in the solution of analogy problems.

Chapter Summary

The priming manipulation of this study failed to confirm the hypothesis set out at the beginning of this chapter. Regardless, the pattern of modest priming effects that occurred across analogy types in this study suggests a role of the association types in the solution of analogy problems. The three noninclusive, nonspecific analogies (part-part, same class and metamorphosis types) all benefitted from this priming manipulation, indicating that the extra inference required of noninclusive analogies is of psychological consequence to their solution process. The priming of the super/subordinate analogy type showed that this association type is more easily recognized, remembered, and used across analogy problems than the others in this experiment. However, the limited success of priming in this experiment probably indicates that the processing of specific word attributes consumes a major portion of the cognitive resources required to solve analogy problems, and that the processing demands of these word attributes may have distracted subjects from attending explicitly to the association types in this experiment.

The role of association types in solving analogy problems was further confirmed by the latency differences between different analogy types. Hypotheses regarding each of the three dimensions of analogy types in the typology cube of Figure 1 were all again confirmed in this experiment. With these results, the main findings regarding the distinctiveness of the analogy types studied in this thesis have recurred in four experimental conditions: recognition, free recall, random presentation and blocked presentation conditions.

CHAPTER SEVEN
EXPERIMENT 3: MANIPULATING WORD ORDER

Overview

This chapter reports an experiment that examined how solving analogy problems is influenced by word order. For example, the original analogy **hand : palm** as **foot : sole** was presented as **palm : hand** as **sole : foot**. This chapter outlines the rationale for this reordering manipulation, describes the method of the experiment, and reports the results. The subsequent discussion focuses on how the manipulation affects subjects' ability to solve different types of analogy problems that varied in specificity and inclusiveness, and further documents the influence of word attributes on the processing of analogies.

Rationale and Hypotheses

The reordering manipulation of this experiment was motivated by questions about the influence exerted by the different semantic associations that define the different types of analogy problems, on the process of solving these problems. The previous priming experiment attempted to discover the amount of time required to process different association types by cuing subjects about the association in problems and observing the solution time savings that resulted. This strategy had the virtue of comparing solution latencies between two experiments (Experiments 1 and 2) that used the same analogy problems as stimuli. The present experiment has this same virtue, and a similar motivation. By reordering the words of these same analogy problems, the nature of some analogy types is altered. Since the same words are used in both the reordered problems and the original problems of Experiment 1, the solution latencies for analogy types in this experiment can be compared to their latencies in

Experiment 1, to directly measure differences resulting from reordering.

This reordering manipulation changed the nature of the association for some of the analogy types used in my experiments, but not others. Analogy types using associations that change with reordering are:

<u>Original Types</u>	<u>Reordered Types</u>
whole-part	part-whole
specific whole-part	specific part-whole
super/subordinate	sub/superordinate
object-action	action-object
metamorphosis (pre-post)	metamorphosis (post-pre)

For these types reordering creates new analogy types which potentially tap into different cognitive processes. For example the whole-part analogy using the word pair **bird : wing** becomes a part-whole type when the words are reordered as in **wing : bird**.

In contrast, for some analogies reversing the order of the words within pairs does not change the nature of the association and so does not alter the analogy type. This is true for part-part, specific part-part, and same class analogies. For example, the part-part word pair **fingers : palm** exemplifies the same part-part type as the pair **palm : fingers**.

The most general hypothesis I propose for the analogy types that do change with reordering is that the reordered problems should cause subjects to use different cognitive processes, and should therefore produce different solution latencies. A more precise hypothesis is that reordering whole-part and super/subordinate problems reduces their solution latencies. This proposal follows from the notion that a whole object, for example, is more distinctly identified by one of its parts than a part is identified by the name of the whole object to which it belongs. For example, **bumper** more distinctly identifies **car** as its whole object than **car** identifies **bumper** as one of its parts. This idea was presented earlier in this thesis where Collins and Quillian's (1969) semantic memory model illustrates that a subordinate object like **trout** more distinctly identifies its superordinate category **fish**, than **fish** serves to identify **trout** (see Figure 2).

Like the specificity hypothesis proposed in Chapter Five, the present hypothesis proposes that an analogy problem specifying its solution to a greater degree (eg. part-whole problems) will be more readily solved than a problem that evokes a larger set of potential solutions (eg. whole-part problems). The greater constraint on the set of solutions for reordered association types manipulation is referred to as the increased *directiveness* of these associations in reordered problems. Directiveness differs from specificity because with specificity this constraint results from the similarity between the two word pairs that make up each problem whereas *directiveness* is a characteristic of a word pair. In short, directiveness can be manipulated *within* a word pair and is therefore a property of the association, whereas specificity can be manipulated *between* word pairs and is therefore a property of the analogy.

Hypothesis 3.1: Reordered analogy problems from whole-part and super/subordinate types will be more quickly solved than the originally ordered problems in Experiment 1.

In the case of specific whole-part analogies reordering is not expected to alter latencies because it is assumed that the specificity of these analogies already constrains the size of the set of potential solution words to a very small set. It is therefore unlikely that increasing the directiveness of the association in these problems could improve the processing efficiency already existing. That is, the role of the word attributes matched between word pairs has such a powerful role in enabling the very efficient processing of these problems that the role of the association's directiveness is expected to be minimal. By this view, specific whole-part analogy problems such as **hand : palm** as **foot : sole** should be solved with equal speed when they are reordered to the specific part-whole form **palm : hand** as **sole : foot**.

Hypothesis 3.2: Reordering will not affect the latencies of specific part-part or specific whole-part analogies.

Although the nature of the object-action association is also altered with reordering, no prediction was made concerning analogy problems of this type because it was unclear which ordering of the association would be more directive. That is, no prediction was made regarding which set of potential solution words would be smaller: the number of actions that an object has associated with it, or the number of objects associated with an action. Likewise, no prediction of reordering effects was made for metamorphosis analogies, for the same reason.

Method and Stimuli

The general method used in this experiment was similar to that of Experiment 1, for both the recognition and recall paradigms (Experiments 3A and 3B, respectively). Only the stimuli were altered. This alteration was a very simple one. Each analogy problem was altered such that the positions of the first and second words were switched, and the third word of the analogy stem was switched with the solution word previously presented among the four answer alternatives. For example, an originally presented problem such as

CAR : WHEEL
BOAT :

1)STONE 2)GRIND 3)MAST 4)GUM

would be reordered to the form:

WHEEL : CAR
MAST :

1)STONE 2)GRIND 3)BOAT 4)GUM

The recognition paradigm used the same four versions of the eighty problem stimulus sets originally used in Experiment 1A, including the same incorrect answer alternatives (distracters) for each problem. Some of the distracters in the reordered problems were replaced by those from other problems because they were associated with the newly positioned third word. In such cases the original distracter words were re-assigned to other problems to ensure that the same words were used in both experiments. Practice test stimuli were reordered in the same way. All other points of method in the practice test and main test repeated the method of Experiment 1.

Results

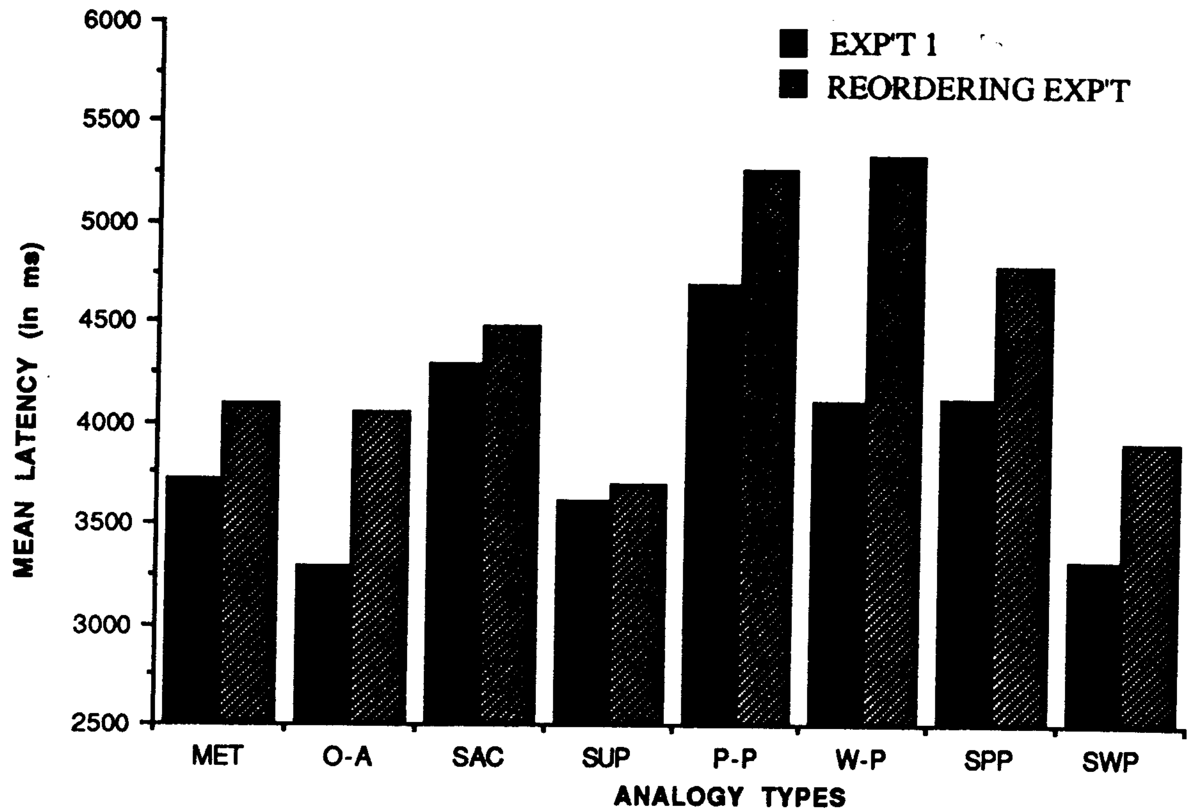
Performance was scored, and the results were analyzed, as in the preceding experiments. For all statistical tests the alpha level was set at .05. The results are reported in three sections. The first two sections concern the effect of reordering on solution latencies by comparing data between this experiment and Experiment 1. The first section does this for the analogy types that form the top tier of Figure 1, separately for the two paradigms. The second section reports this analysis for the analogy types from the lower tiers of the functional/structural dimension. In the final section errors are briefly analyzed.

Table 10

Mean Solution Latencies From Experiment 1 and the Reordering Experiment

Experiment	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
1A (recognition):	3717(185)	4291(290)	4686(312)	4115(224)
3A (recognition):	4096(292)	4479(330)	5268(384)	4783(355)
1B (recall):	3630(238)	5279(326)	5695(372)	4646(283)
3B (recall):	5170(471)	6008(586)	6999(566)	5610(351)
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
1A (recognition):	3286(119)	3603(171)	4109(242)	3316(159)
3A (recognition):	4053(206)	3692(171)	5332(532)	3905(298)
1B (recall):	2919(151)	4225(342)	4736(347)	3179(190)
3B (recall):	4006(259)	3674(273)	4824(404)	4120(261)

note. latencies are given in milliseconds.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 14. Mean solution latencies of recognition data from Experiment 1 and the Reordering Experiment.

Effects of Reordering on Top Tier Analogies

The Recognition Paradigm

Figure 14 presents the means of the median latency scores averaged across subjects in this experiment, together with the corresponding values from Experiment 1. These means are listed in Table 10, together with their standard errors. For the analogy types from the top tier of the cube in Figure 1 (found on the left side of Figure 14), the latencies from this reordering experiment are consistently longer than those of Experiment 1. Although this figure shows latency increases for all four of these analogy types, it shows the largest increase for nonspecific whole-part analogies. In fact, this mean latency for reordered whole-part analogies is larger than that of part-part analogies, which is an unique outcome in the experiments reported so far.

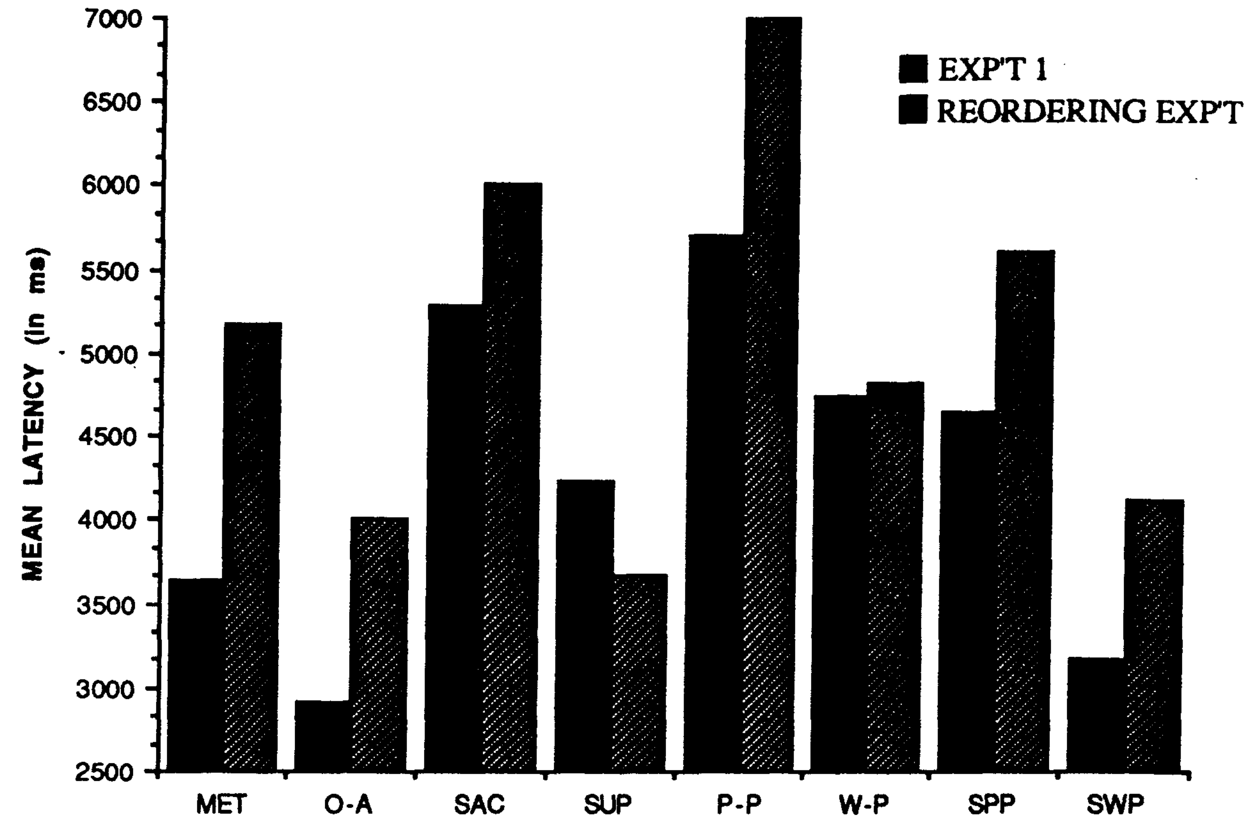
A mixed design 2 X 2 X 2 ANOVA was performed to test the effect of reordering across the two levels of specificity and the two levels of inclusiveness. The overall difference in latency scores between the two experiments was marginal, $F(1,46) = 3.2$, $MS_e = 8700488.0$, $.1 > p > .05$, and this factor did not interact with specificity or inclusiveness (both F values < 2). In addition to the longer latencies in the reordering experiments, a marginal three-way interaction among inclusiveness, specificity and paradigms was also present, $F(1,46) = 2.9$, $MS_e = 543254.3$, $.1 > p > .05$. In addition to the effects of reordering, this analysis showed main effects of specificity $F(1,46) = 54.5$, $MS_e = 590386.1$, and of inclusiveness, $F(1,46) = 21.2$, $MS_e = 679223.6$, and an interaction between these factors $F(1,46) = 7.5$, $MS_e = 543254.3$.

In order to determine which analogy types showed significant latency changes with reordering, this marginal three-way interaction was examined for simple main effects of priming on each of the four analogy types. These analyses found a significant effect of reordering on the nonspecific whole-part analogies only, $\underline{F}(1,46) = 6.83$, $\underline{MS}_e = 2628338$, $\underline{p} < .05$. The lack of significant effects for other types (all $\underline{F}$ values < 3, $\underline{p} > .1$) was surprising since all these types showed an increase in mean latencies of more than .5 seconds. The apparent reason for this is the great variability of scores from the reordered experiment. As Table 10 shows, all the standard errors for these means increased substantially, and for the two whole-part types these values more than doubled. Thus, although latencies showed large increases with reordering, the responses of subjects in the reordering experiment were so variable across subjects that only the 1223 ms increase found for the whole-part problems was statistically reliable. This finding regarding whole-part analogies directly contradicted Hypothesis 3.1 regarding the effect of directiveness in whole-part and part-whole associations. Hypothesis 3.2 regarding the two specific analogy types is contradicted by the large latency increases for these problems, although this effect was not confirmed by statistical analyses.

The Recall Paradigm

The latency scores for these four analogy types in the recall paradigm of this experiment and Experiment 1 are presented in Figure 15 (on the left side), and in Table 10 together with their standard errors. The latencies from the reordered experiment are longer than those of Experiment 1 for all analogy types except the super/subordinate type. The usual effects of inclusiveness and specificity are also apparent. As in the data for the recognition paradigm the latency changes with reordering do not appear to be equal for these four analogy types, apparently due to exceptional latency changes for nonspecific whole-part analogies. Unlike the data for the recognition paradigm, however, the latency increase for this analogy type appears to be much smaller than for the other three analogy types.

A mixed design, 2 X 2 X 2 ANOVA like the one performed on the data of



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 15. Mean solution latencies of recall data from Experiment 1 and the Reordering Experiment.

the recognition paradigm showed that solution latencies of the reordered experiment were longer than those of Experiment 1, $\underline{F}(1,46) = 4.1$, $\underline{MS}_e =$ 7878745. Furthermore, this reordering effect showed a marginal interaction with inclusiveness $F(1,46) = 3.9$, $\underline{MS}_e = 1154448.0$, $.1 > \underline{p} > .05$. There was no significant two-way interaction between reordering and specificity ($F < 1$), but the three-way interaction among inclusiveness, specificity and experiments was marginal, $\underline{F}(1,46) = 3.1$, $\underline{MS}_e = 1447936.0$, $.1 > \underline{p} > .05$. This analysis also found the usual main effects of specificity, $\underline{F}(1,46) = 31.0$, $\underline{MS}_e = 2116474.0$, and inclusiveness, $\underline{F}(1,46) = 97.0$, $\underline{MS}_e = 1154448.0$, but no two-way interaction between these factors ($F < 1$).

Simple main effects of reordering were tested on the four analogy types in this analysis. Part-part problems showed greater latencies with reordering, $\underline{F}(1,46)$, = 6.46, $\underline{MS}_e = 3149401$, as did the two specific types; $\underline{F}(1,46)$, = 3.38, $\underline{MS}_e = 3149401$, for specific part-part latencies, and $\underline{F}(1,46)$, = 3.38, $\underline{MS}_e =$ 3149401, for the specific whole-part type. Again, Hypothesis 3.2 was contradicted by these results. Furthermore, since nonspecific whole-part problems did not change with reordering ($\underline{p} > .1$), Hypothesis 3.1 was also left unsupported. The great variability of scores from the reordered experiment is again notable. To illustrate, the mean latency for specific analogy types increased by almost one full second, yet these differences were only marginally significant.

The Effect of Reordering Analogy Types on the Lower Tiers

The mean latency values for these analogy types are plotted in Figures 14 and 15 for recognition and recall paradigms, respectively. The means are also listed together with their standard errors in Table 10. These data were initially analyzed, as in previous experiments, by a pair of 2 X 3 X 2 ANOVA comparing the two experiments, the three levels of the functional/structural dimension, and the two levels of inclusiveness, separately for each paradigm. In neither paradigm was the effect of reordering significant as a main effect (both F values < 3, p > .095). In both paradigms, however, this factor interacted across analogy types. In the recognition paradigm this took the form of a significant interaction with the functional/structural dimension $F(2,92) = 4.5$, $MS_e = 784562.1$, and a marginal interaction with inclusiveness $F(1,46) = 3.0$, $MS_e = 583769.0$, $.1 > p > .05$. In the recall data the effect of reordering interacted marginally with the functional/structural dimension $F(2,92) = 4.1$, $MS_e = 2111621.0$ and inclusiveness, $F(1,46) = 9.4$, $MS_e = 1838569.0$.

The analysis of the effect of reordering on these data proceeded with tests for simple main effects on each analogy type. The results of these tests were quite similar in the two paradigms. In neither paradigm did super/subordinate or same class types show a significant change in latency with reordering ($p > .1$), contrary to Hypothesis 3.1 regarding the role of directiveness in super/subordinate associations. In the recall paradigm latencies increased marginally with reordering for both object-action, $F(1,46) = 3.9$, $MS_e = 3502911$, $.1 > p > .05$., and metamorphosis types, $F(1,46) = 7.8$, $MS_e = 3502911$, $.1 > p > .05$. In the recognition paradigm this marginal effect occurred for object-action problems only, $F(1,46) = 3.5$, $MS_e = 2026258$, $.1 > p > .05$.

Analysis of Errors

As in the previous experiments, errors in the recognition paradigm consisted of incorrect keypad presses. In the recall paradigm errors consisted of spoken answers which were uninterpretable, or were judged inconsistent with the association type exemplified by the problem's first word pair. Like the latency data, the error rates of this experiment provide evidence that the reordered stimuli were generally more difficult than the original problems from

Experiment 1. Error rates for the present experiment were 7.9% and 14.6%, for the recognition and free recall paradigms, respectively. These figures represent increases of 6.3% and 4.2%, respectively, from the error rates of Experiment 1.

Like the error patterns of the previous two experiments, these error data also reflect the relative difficulty of noninclusive and nonspecific problems. Of the errors produced by subjects solving the top tier analogy types 33% were committed on specific problems and the non-specific types accounted for 67%. This distribution represents a significant deviation from chance, $p < .01$, according to Chi-square analysis. Unlike previous experiments, however, the percentage of errors committed on noninclusive analogy types (53% of all errors) was not significantly greater than that committed on inclusive types (47%), $p > .1$. Error rates for each reordered analogy type appear in Appendix M.

Summary Of Results

The results of the reordering manipulation were unexpected. Neither whole-part nor super/subordinate types showed faster solution latencies with reordering, as was predicted by Hypothesis 3.1. In general, reordering increased the latencies of the four analogy types on the top tier of the cube in Figure 1, including the specific types that were predicted to be unchanged by this manipulation according to Hypothesis 3.2. The latency increases found for reordered part-part and same class types contradict the basic assumption that these analogy types would be unaffected because reordering would not alter the nature of the associations in these problems. These results are all clearly apparent in Table 11, which shows the mean solution latency increase for reordered problems of each analogy type.

Perhaps the most puzzling finding is the inconsistency of reordering effects on the nonspecific whole-part analogies in the two paradigms. In both paradigms

Table 11

Mean Latency Increase in the Reordering Experiment From the Latencies of Experiment 1, By Analogy Type

Paradigm	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
Recognition:	396	188	†581	†668
Recall:	1500	730	†1305	†915
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
Recognition:	767	*88	*1222	†587
Recall:	1068	*-536	*107	†941

notes. latencies are given in milliseconds.
† indicates analogies from the top tier of Figure 1 for which reordering showed a consistent effect in each paradigm.
* indicates analogies for which Hypothesis 3.1 postulates reduced latencies.

Hypothesis 3.1 is left unsupported since latencies for this analogy type did not decrease. However, the very large increase in latencies for these types in the recognition paradigm (1222 ms) contrasts markedly from the minimal increase shown in the recall paradigm (107 ms). Speculation about how the processing of these problems could be so different in the two paradigms will be offered in the following discussion section.

Among the analogy types of the lower two tiers, a general tendency toward longer latencies for reordered analogies was also found, although this effect was statistically significant only for the types on the lowest tier. Hypothesis 3.1 regarding the super/subordinate type was not confirmed, since statistical tests showed that latencies for these problems did not change significantly in either paradigm. However, a notable tendency toward faster latencies did appear in the recall paradigm.

Discussion

Attempts to demonstrate the role of directiveness in analogies by altering the nature of their association types through reordering was not successful, since neither part-whole nor sub/superordinate analogies showed latencies fast enough to support Hypothesis 3.1. Two major surprises appeared in the results instead; latencies for most analogy types increased with reordering, and the effect of reordering on whole-part analogies was very inconsistent between paradigms.

Both of these surprising results probably reflect the influence of the particular words used in these problems. This conclusion may initially seem unfounded, since reordered problems were constructed using the same words as the original problems of Experiment 1. However, because these words were reordered, different words appear in the third word position (and for all other word positions) for the reordered problems. Since these third position words have a very important role in cuing subjects about the solution, and since the reordered problems were not screened to ensure their consistent interpretation (as were the original problems), longer latencies for reordered analogies may have resulted because the particular words appearing in their third word positions were relatively ineffective solution cues. In the first section of the present discussion, this explanation will be used to account for the general latency increase resulting from reordering. In the second, the effects of reordering on whole-part analogies will be addressed. In the final section, general conclusions will be drawn from this discussion.

Explaining the General Latency Increase With Reordering

In this section, the role of word attributes in the problem solving process is used to account for the general latency increase with reordering. Before this explanation is presented, however, two other potential explanations are briefly addressed to highlight their inadequacies. The first suggests that these latency increases might themselves be a product of changes made to the association types in these problems. This explanation seems implausible for three reasons. The first is that these increases occurred even for analogy types such as part-part which did not change with reordering. Second, similar increases occurred for both specific whole-part and specific part-part analogies even though reordering changed the nature of the former but not the latter type of problem. Thirdly, similar latency increases occurred for most analogy types, many of which vary significantly from each other according to their solution latencies in Experiment 1. Given the diversity of analogy types affected, if these latency increases are due to a characteristic of the associations in these problems, this characteristic must be common to many diverse association types. In fact, similar latency increases occurred for the analogy types at both end points of each of the three analogy dimensions in the cube in Figure 1. The existence of such a common association characteristic, affected by reordering, seems implausible.

The second potential explanation to be debunked here is that the general latency increases may simply be a product of subject differences. That is, the longer solution latencies stem from the subjects in Experiment 3 being generally less skilled at solving analogies than the subjects in Experiment 1. Two pieces of evidence argue against this possibility. One is that these effects are highly consistent for both recall and recognition paradigms of Experiment 3, in which different groups of subjects were used. The second is that while this latency increase was found for many analogy types, some failed to show this effect, even though the same subjects were tested with all types.

This leaves the role of word attributes as the most plausible explanation of this general latency increase. This explanation is based on the possibility that the repositioning of words within reordered problems placed different words in their third word position. Since these words weren't selected by the same criteria as those in the original analogy problems, they may have been less effective cues for the solution of these reordered problems.

What might be the nature of the difference between these words and those used in Experiment 1? Two possibilities exist. First, it is possible that the third words in the reordered problems simply don't elicit the type of associates targeted in their problems as readily as the words in the original problems did. For example, in the original part-part problem **hull : mast** as **bumper : wheels, bumper** may elicit other parts of cars more readily than **wheels** would when this analogy becomes reordered. That is, **wheels** may more readily elicit other association types such as object-action (**wheels : roll**) or whole-part (**wheels : rim**). The activation of these irrelevant associates would lengthen solution latencies for these problems by burdening subjects with the task of processing them.

The second way that the third words of reordered problems might differ from those of original problems is that they may be more prone to being incorrectly interpreted. For example, when the part-part problem **lungs : skin** as **gills : scales** is reordered, the new third word **scales** can be interpreted in at least two ways, each forming a different type of association with the third word. One interpretation forms a part-part association (as in **scales : gills**), the other forms an object-use association (as in **scales : weigh**). If the processing system first activates an interpretation of **scales** irrelevant to the part-part association in the first word pair, the realization of the relevant interpretation of **scales** (as a part of fish) will be delayed, and solution latencies for this reordered problem should increase accordingly. Note that this misinterpretation would lead to a similar latency increase for these problems in both paradigms because i) this mapping disruption should delay the appropriate interpretation of **scales** in both paradigms, and ii) after this occurs further processing should continue unaffected in both paradigms. This type of word ambiguity and the resulting processing disruption will now be contrasted with a second type proposed to account for the results of reordered whole-part analogies.

Explaining Inconsistent Latency Changes Between Paradigms For Whole-part Analogies

To explain the inconsistent effect of reordering on whole-part problems in the two paradigms, a second type of word misinterpretation is described. In this case, the multiple interpretations of the third position word all suggest associates that are compatible with the association type targeted in the problem. For example, in the reordered part-whole analogy **spine : book** as **lead : pencil**, the third word **lead** can refer to a pencil mark or a type of metal. Both interpretations would elicit associates based on the part-whole association type. In this case if the interpretation irrelevant to the correct answer word is processed first, only latencies in the recognition paradigm will be lengthened. For example, if **lead** is most readily interpreted as a heavy metal, subjects in the recognition paradigm will fail to find a solution word conforming to their initial interpretation of **lead** since the solution choice **pencil** does not associate with this interpretation. These subjects will require additional processing time to re-interpret the problem (particularly the word **lead**) and to select the appropriate solution alternative from among those provided. In the recall paradigm however, since subjects' solutions are not constrained by provided alternatives, the latency of their responses will reflect the time needed by subjects to make their first interpretation of **lead** and to solve the analogy accordingly. For this example such solution responses might include the words **pewter, gasoline, paint, pipe**, and **clay**.

This type of word misinterpretation is proposed as an explanation for the large latency increase found for part-whole problems, in the recognition paradigm only. Evidence of this type of misinterpretation is revealed by an analysis of the reordered part-whole analogy problems used, and in subjects' responses to these problems. For example, the reordered problems eliciting the longest latencies in the recognition paradigm did contain highly ambiguous words in their third position words. One of these was the example presented above to illustrate the ambiguity of the word **lead**. The other is **bristle : brush** as **filter : cigarette**, where responses in the recall paradigm showed **filter** to be more readily associated with **coffee-maker** and **swimming pool** than with **cigarette**. These examples, and several others among the reordered part-whole problems, suggest a potent role of word ambiguity in creating longer solution latencies for whole-part problems in the recognition paradigm, as were found in this experiment.

General Conclusions

The goals and outcomes of this experiment have some broad similarities to those of the previous experiment. In Experiment 2 priming was designed to demonstrate the role of association types in the processing of analogy problems, but this demonstration was obscured by the unexpected role of word attributes which apparently obstructed subjects' acquisition of the information necessary to prime analogy types. In the present reordering experiment evidence for the role of association types was sought by changing the nature of the association in analogies using the same words as the original problems. Again, the role of word attributes was apparent in the results, possibly because the different third words can be so variably interpreted, and possibly because they evoked irrelevant associations.

Still the results of the present experiment show hope of demonstrating the effect of the reordered association type. Hypothesis 3.1 proposed that reordering would reduce the processing time for whole-part and super/subordinate analogies. Since the effect of reordering on these types was exceptional compared to the other types, it is possible that this reordering manipulation did influence their latency scores as predicted. That is, it is possible that these scores would have shown significant increases comparable to those of the part-part and object-action analogies if the added directiveness of their association had not moderated their overall processing demands.

This experiment has unexpectedly highlighted effects of word attributes in analogy problem solving. The results suggest that the words used in the third position may have a role in evoking particular types of associates more quickly than others. They also serve as a reminder that the words of a problem are not equally influential in the solution process, and that the solution cues provided by third position words are especially important. The next two experiments attempted to isolate the effects of word attributes from the role of association types. The lessons learned from this experiment influenced the design of these experiments greatly. In Experiment 4 the identity of the third position words were controlled between specific and nonspecific problems to determine if the particular words used in Experiment 1 caused the specificity effect. In both Experiments 4 and 5 the third position words were retained from the original analogies in order to avoid the uncontrolled variability that seemed to occur in this experiment. Both Experiments 4 and 5 are reported in the next chapter.

CHAPTER EIGHT : MANIPULATING THE SIMILARITY OF WORD PAIRS WITHIN PROBLEMS

Overview

The experiments presented in the previous three chapters investigated the role of the association type in an analogy problem on the processing of its solution. Experiments 2 and 3 unexpectedly showed an important influence of the particular attributes of the words contained in these problems. The present chapter describes two experiments in which attempts were made to demonstrate the role of word attributes on analogy problem solving processes, and to show that this role operates similarly across analogy problems using different association types.

Like Experiment 1, Experiment 4 demonstrates that a processing advantage results from the use of closely matched attributes in the two word pairs in a problem, and does this using whole-part and part-part analogy types. In fact, Experiment 4 demonstrates this effect by presenting subjects with alterations of the same specific part-part and specific whole-part problems used in Experiment 1. These problems were altered to use the same third position words in both specific and nonspecific conditions in an attempt to hold constant the attributes of these words as a cause of latency differences between conditions. If the specificity effect is evident among the problems used in Experiment 4, then specificity is not an artifact of a coincidentally strong connection between the third word and the association type appearing in specific problems. This would support the explanation proposed by my processing model that the processing advantage resulting from specificity is caused by the close match of word attributes between word pairs within a problem.

Experiment 5 attempted to support this preferred explanation by manipulating the match of a different type of word attribute using problems of the six nonspecific analogy types on the front face of the cube in Figure 1. New problems were created by combining first word pairs with the second word pairs of other problems of the same type. The critical difference between these new problems and the originals was the degree of similarity between the subject matter of the two word pairs. Whereas each of the original problems was constructed using word pairs of a similar subject matter (eg. **car : wheel** as **boat : mast**), the word pairs within each new problem addressed two more divergent content areas (eg. **hand : palm** as **boat : mast**). That is, subjects were forced to greatly switch topics, or realms, when transferring information about the first word pair to the second word pair in each problem.

This manipulation was performed to demonstrate that reducing the similarity of subject matter between word pairs impedes subjects' processing of analogy problems. The discovery of this finding would lead to the conclusion that the word attributes identifying the referents of words as objects of a particular taxonomic class are used in the process of analogical transfer, and that this process is enhanced when these attributes are closely matched between word pairs. Since this manipulation and its effect would be similar to that produced by matching the spatial attributes of words in specific and nonspecific problems in Experiment 1, the realm switching manipulation of Experiment 5 is characterized as another specificity manipulation.

Experiment 4: A Manipulation of Solution Specificity

This experiment was conducted to test the explanation that specific problems are more quickly solved than nonspecific ones because of the similarity between the two word pairs. In Experiment 1 this has been demonstrated by the latency differences between specific and nonspecific problems using both whole-part and part-part analogy types. However, because different words were used in the third position of specific and nonspecific problems, and since the reordering experiment demonstrated the potentially strong role that these third position words can play in the solution process, this present experiment was conducted to address the possibility that the specificity effect demonstrated in Experiment 1 resulted from the particular words used. This possibility exists because the third words in the specific analogy problems might have provided subjects with stronger cues eliciting associates consistent with the association type in these problems. This experiment addressed this possibility by demonstrating the specificity effect in whole-part and part-part analogy types using specific and nonspecific problems constructed with the same third position words.

This present experiment used the same specific part-part and specific whole-part problems from Experiment 1. These analogies contain word pairs depicting objects with a same spatial relationship between them in both pairs, as in the specific analogy **hand : palm** as **foot : sole**, for example. These word attributes matched between pairs were expected to create relatively fast solution latencies for these problems. Also, like Experiment 1, the two word pairs in the nonspecific problems do not specify the same spatial relationship between the objects they depict. For example, the nonspecific analogy **desk : drawer** as **foot : sole** uses the same type of association (whole-part) in both word pairs, but the word attributes specifying the spatial relationship of the objects depicted in them are different. By comparing subjects' performance on these two versions of part-part and whole-part analogies, the effect of these specific spatial attributes on solution latencies will again be tested.

The present experiment is unlike Experiment 1 however, because the nonspecific problems used in this experiment were constructed using the same third words as the specific problems (i.e. **foot** in the example above). This allows the present experiment to separate the role of the attributes matched between word pairs, and the role of the third words, in creating the processing advantage demonstrated for specific analogy types. If the same specificity effect is demonstrated by the specific and nonspecific problems of Experiment 4, which are constructed from the same third words in both cases, the processing advantage found for specific problems could not have been caused as an artifact of these words.

Hypothesis 4.1: Specific analogy problems will be solved more quickly than nonspecific problems, even when both types use identical words in their third word positions.

Method

Stimuli

In this experiment, only analogy types from the top tier of Figure 1 were used. The ten specific whole-part and ten specific part-part problems from Experiment 1 were used. The ten nonspecific problems of each type were derived from the specific problems, by substituting two new words for the first word pair in each case. For example, from the original specific whole-part analogy **chair : legs** as **car : wheels**, the third word **car** was matched with **desk : drawer** to create the analogy stem **desk : drawer** as **car : _____ .** This created a nonspecific analogy since no single specific solution word is readily apparent. In most cases the new, nonspecific analogy also contained the same fourth word as the original analogy. In this example the new analogy would become **desk : drawer** as **car : wheels**. However, for three of these derived, nonspecific analogies it proved awkward to construct such a problem using the same fourth word used in the specific problem, so a new fourth word was used in the nonspecific problem. Appendix N contains the forty analogy problems used in this experiment.

Only multiple choice problems were used, as only the recognition paradigm was run. The distracter words for the new nonspecific problems were chosen from the same pool of words used as distracters in the original set of analogies.

Four versions of the forty problem stimulus set were constructed in order to ensure that the correct answer was presented in each of the four alternative positions, for each analogy. Each of these four sets of problems were then divided into two lists of twenty problems each, in such a way that none of these lists contained a specific and nonspecific analogy problem constructed with the same third word. In order to arrange this, the first five analogies from the original, specific whole-part and specific part-part analogy types appeared in one list. The other five analogies of each type appeared in this same list in their newly created, nonspecific form. The remaining twenty analogy problems appeared in the second list from each problem set. Appendix N indicates which problems in the stimulus set were assigned to each of the two lists.

Design

The 24 subjects used in this experiment (12 males, 12 females) were assigned in equal numbers to receive each of the eight lists of analogy problems (two lists from each of four stimulus sets). Therefore, twelve subjects received each analogy in its specific form and twelve received it in its nonspecific form. Since five problems from each analogy type were included in each list, each subject received five problems of each type.

Procedure

At the beginning of the session, subjects were given the same basic instruction sheet as in the previous experiments and were informed that there would be two parts to the experiment. The first part consisted of solving the twenty analogy problems from one of the stimulus lists. The practice test in this experiment consisted of the eight problems from the practice test in Experiment 1 that illustrated specific and nonspecific, part-part and whole-part analogies. Following this, each subject was tested on one of the stimulus lists. All other points of procedure were performed according to the general method described in Chapter Three.

Subjects were then moved on to a second part of their task in which they were asked to sort the eighty problems used in Experiment 1 into groups of their own construction. This task will be described in Chapter Nine on Experiment 6.

Results

For each subject, the median solution latency was calculated from the five problems presented for each analogy type. Mean values were then calculated from these medians by averaging scores for each analogy type across the 12 subjects who received the same analogy problems. That is, one set of means was calculated from the data of subjects who received the first list drawn from each stimulus set, and another was calculated from the data of those who received the second list from each set. These values are presented in Table 12. A mixed design, 2 X 2 X 2 ANOVA tested the results from the two lists of the stimulus set, specificity (distinguishing specific from nonspecific analogies), and inclusiveness (distinguishing the part-part from the whole-part analogies). The results of the ANOVA showed that the two halves of the stimulus set were responded to similarly, $\underline{F}(1,22) = 3.2$, $.1 > \underline{p} > .05$. For this reason, Figure 16 presents the mean solution latencies of the four analogy types, collapsed between the two stimulus lists. Please note that although these means are plotted with the latencies for these analogy types in Experiment 1, the means from Experiment 1 are not directly comparable to those of the present experiment for two reasons: i) in the present experiment fewer stimuli (five) were presented to each subject, and ii) for the nonspecific part-part and nonspecific whole-part analogies, the problems used were not the same between experiments. For these reasons no statistical comparisons between experiments were made.

The results of this ANOVA clearly showed that specific problems were solved significantly faster than the newly created nonspecific problems, $\underline{F}(1,22) = 13.3$, $\underline{MS_e} = 2300602$. An effect of inclusiveness was also found, $\underline{F}(1,22) =$

Table 12

Mean Solution Latencies From Experiment 1 and the Specificity Experiment

Experiment	Analogy Type	
	Part-Part	Spec. Part-Part
Exp't 1:	4686	4115
Specificity Exp't (first list):	4712	4260
Specificity Exp't (second list):	6411	5339
Specificity Exp't (mean):	5562	4799
	Whole-part	Spec. Whole-part
Exp't 1:	4109	3316
Specificity Exp't (first list):	5006	3778
Specificity Exp't (second list):	5710	3938
Specificity Exp't (mean):	5358	3858

note. latencies are given in milliseconds.

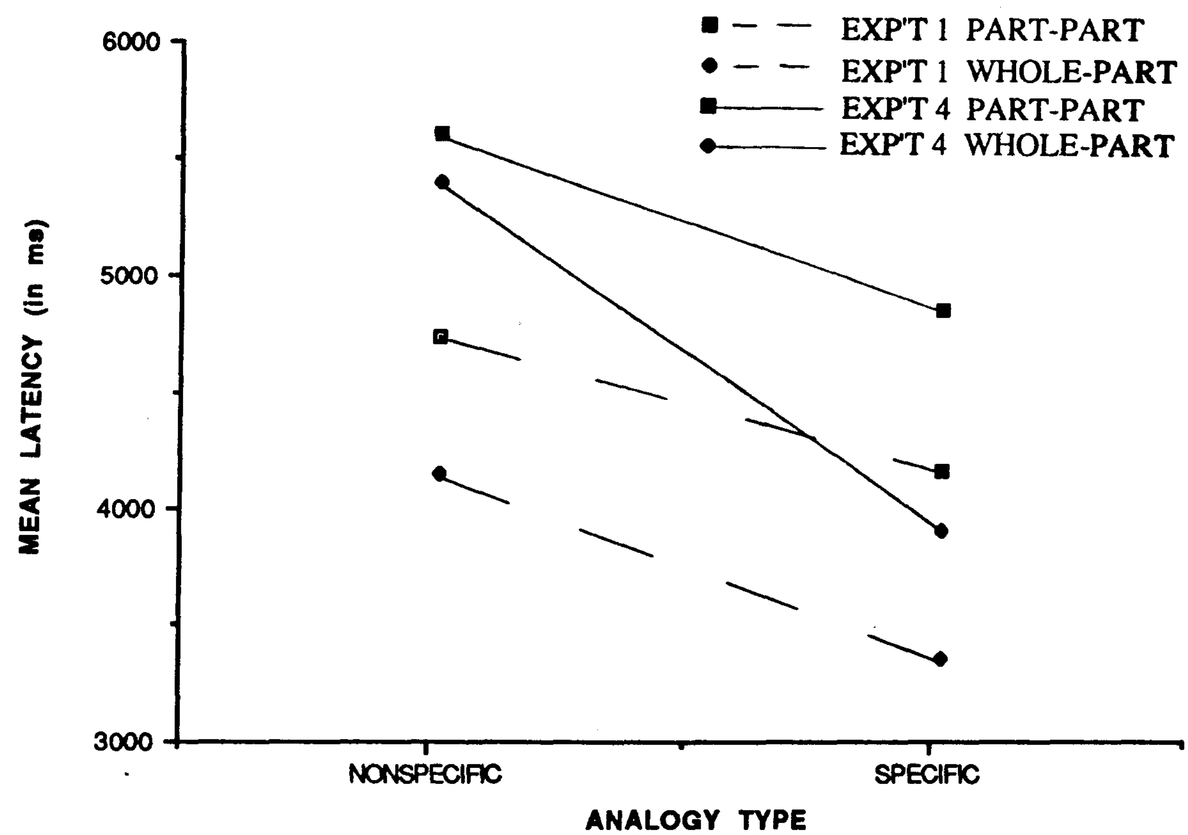


Figure 16. Mean solution latencies of top tier analogy types from Experiment 1 and the Specificity Experiment (Exp't 4).

5.0, $\underline{MS}_e$ = 1567290. The interaction between these factors was also significant, $\underline{F}(1,22) = 4.5$, $\underline{MS}_e$ = 730042.1. As Figure 16 illustrates, this interaction showed a greater difference in solution latencies between the part-part and the whole-part analogies for specific analogies than for nonspecific ones.

Only six errors were committed by subjects in this experiment, representing 1.25 percent of responses. No further analysis of this data was performed.

Discussion

The results of this simple experiment confirmed Hypothesis 4.1. Nonspecific analogies formed using the same third words of the specific analogy problems in Experiment 1 elicited significantly longer solution latencies than the original specific problems. That is, the specificity effect was again demonstrated for both part-part and whole-part analogy types.

This finding supports the claim that the specificity effect found in Experiment 1 is not an artifact created through the use of third position words strongly connected with the association type used in the analogy. Solution latencies were longer for the nonspecific problems of this study even though their third words were identical to those in the specific versions of these analogies. This result supports the view that the specificity effect is caused by the matching of similar attributes between first and third words within a problem.

Experiment 5: Realm Switching

Rationale

In the experiments presented thus far, part-part and whole-part analogies are the only types distinguished on the specificity dimension. Specificity is manipulated in these types by varying the degree to which the spatial relationship between the objects depicted by first word pair matches that of the second word pair. This experiment attempted to demonstrate that matching a different type of attribute may also result in faster solution times. The attributes manipulated are those that identify the taxonomic identity of objects.

In the original problems these attributes were considered closely matched between word pairs because problems were constructed from word pairs closely related in subject matter, as are each of the following super/subordinate analogies: **sport : soccer** as **game : monopoly** and **flower : rose** as **tree : maple**. In the present experiment this type of similarity between word pairs was reduced by switching the first word pairs among these analogies. For example, this manipulation creates the following two problems from the originals listed above: **sport : soccer** as **tree : maple** and **flower : rose** as **game : monopoly**.

My processing model proposes that the transfer of information to the second word pair is performed by seeking out the details of the association recorded in the first word pair. Since this process employs a procedural type of processing if these details are found, reducing the taxonomic similarity of word pairs in the problems of the present experiment was expected to reduce the efficiency of the mapping and application components of their processing. In this way, this type of attribute mismatch is expected to influence processing the same way that the mismatch of spatial attributes between word pairs lengthened solution times for nonspecific problems in Experiment 1. Thus, the primary hypothesis tested in this experiment is that this realm switching manipulation reduces the specificity of these problems which should, in turn, cause subjects to respond more slowly than they did to the original problems in Experiment 1. The analogies used in this experiment were the six non-specific types from the front face of the cube in Figure 1. The two specific analogy types were not used in this manipulation since switching the realms of word pairs within these problems would necessarily reduce the spatial/structural similarity of the two associations, as well as the similarity of subject matter, and therefore would not test hypothesis 5.1.

Hypothesis 5.1: Realm switching will result in longer latency times than those of Experiment 1, for all six analogy types on the front face of the cube in Figure 1.

The solution latencies for problems produced by this realm switching manipulation performed on same class and super/subordinate analogies were of particular interest because this manipulation within these analogy types was essentially a manipulation of the same characteristic that defines the associations they are based on (i.e. taxonomic identity). To illustrate, in a realm switched analogy problem such as **sport : soccer** as **tree : maple,** the basis of the association between **tree** and **maple** is taxonomic in nature, and the reduced similarity between word pairs in this problem relative to the similarity of the word pairs in an original problem like **flower : rose** as **tree : maple** is also taxonomic in nature.

That is, in realm switched problems the categories of the objects involved (eg. **sport** and **tree**) are more taxonomically distant from each other than in the originals (eg. **flower** and **tree**). From a theoretical view, the realm switching manipulation of same class and super/subordinate problems is a test of the extent to which the attributes signifying the taxonomic class of an object are similar among words depicting objects from different taxonomic classes. If these attributes differ significantly among words of different classes, subjects should respond to realm switched problems as if they were nonspecific problems (i.e. slowly). If they are similar, realm switched problems should elicit latencies of similar speed to those in Experiment 1 (i.e. no specificity effect should occur).

The effect of this realm switching manipulation on part-part and whole-part analogies was also of particular interest, because these were the analogy types for which a specificity effect had already been established using attributes regarding the spatial relationships between the words. If solution latencies also increase in these analogies due to realm switching, this would demonstrate that the specificity effect can be induced by more than one type of attribute similarity, in the same problem.

Method

Sixty problems were used; ten from each of the six analogy types on the front face of Figure 1. For the purpose of stimulus design, the ten analogies of each type were randomly divided into two groups of five. For each subgroup, four versions of each problem were created by substituting the first word pair of each analogy with the first word pair from each of the other four analogies in the subgroup. Table 13 shows a subgroup of five super/subordinate problems and the four new realm switched analogies formed from one of the originals. Appendix F indicates which of the original problems were grouped together for this manipulation. Using these problems, four test forms were designed, each with a different realm switched version of each original problem. The method used to create realm switched problems was identical in the two paradigms. For the recognition paradigm the words used as answer alternatives, and the positions of these alternatives, was identical to those in the four forms constructed for Experiment 1.

As a counter-balancing measure, six subjects (3 male and 3 female) received each of these four sets of realm switched problems. As in Experiment 1, the 60 problems were presented in one completely randomized block. All other aspects of the method were the same as the General Method described in Chapter Four.

Twenty-four subjects were run in both recognition and recall paradigms (Experiments 4A and 4B, respectively). These subjects were drawn from the same pool used in other experiments.

Results

The analysis of the data from this experiment is reported in two sections.

Table 13

An Example Of Realm Switched Problems Created From Original Problems Of Experiment 1

	Original Supersubordinate Problems	Realm Switched Problems Generated From Original Problem #1.
1.	flower : rose tree : maple	
2.	furniture : table apliance : stove	furniture : table tree : maple
3.	fruit : banana vegetable : corn	fruit : banana tree : maple
4.	sport : soccer game : monopoly	sport : soccer tree : maple
5.	clothing : sweater jewelry : ring	clothing : sweater tree : maple
		Realm Switched Problems Generated From Original Problem #6
6.	animal : bear bird : crow	
7.	meat : bacon seafood : lobster	meat : bacon bird : crow
8.	professional : lawyer tradesman : welder	professional : lawyer bird : crow
9.	reptile : turtle insect : ant	reptile : turtle bird : crow
10.	hobby : model-building pet : dog	hobby : model-building bird : crow

First, the effect of realm switching on solution latencies was tested separately for each paradigm. A pair of ANOVAs tested the latency changes between this experiment and Experiment 1 for all six analogy types. In the second section, the error data are analyzed. As in the results section of previous experiments, an alpha level of .05 can be assumed for all significant results reported.

A third section on analysis of these data appears in Appendix O where the latency data from the two paradigms are analyzed together, separately for each level of the functional/structural dimension. These analyses show an interaction between the effects of realm switching, the paradigm distinction (recall/recognition), and the inclusiveness dimension, for middle tier analogy types. These analyses appear in Appendix O because the statistical effects are not strong, and their implications do not apply to the central themes of this chapter. In Appendix O these analyses are followed by a speculative discussion of how the interactions created by the realm switching manipulation might provide insight regarding the procedural nature of processing for some analogy types.

Solution Latencies

Solution latencies in this experiment were summarized, as in previous experiments, by calculating the median latency of the ten problems of each analogy type, for each subject. The mean values calculated from the medians of all 24 subjects are presented in Figure 17 and 18 for the recognition and recall paradigms, respectively. Table 14 lists these same means.

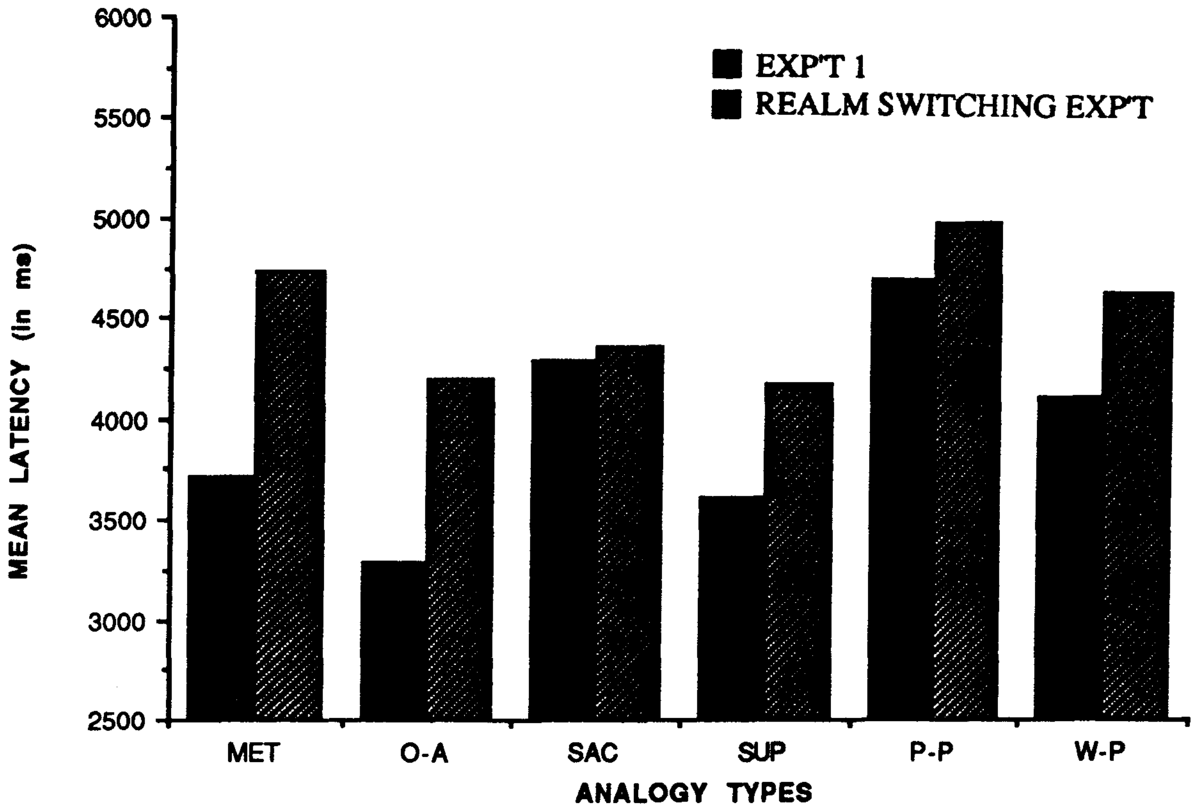
In the data from the recognition paradigm, no main effect of realm switching was found, $F = 2.3$, $p > .1$. However, this factor interacted with the functional/structural dimension, $F(2,92) = 5.9$, $MS_e = 499133.2$, indicating that realm switching increased latencies most for analogy types at the lowest level of this dimension. A marginal three-way interaction between these factors and inclusiveness was also present, $F(2,92) = 2.7$, $MS_e = 197320.3$, $.1 > p > .05$. In order to locate the effect of realm switching more precisely, the simple main

Table 14

Mean Solution Latencies From Subjects Analysis of Experiment 1 and the Realm Switching Experiment

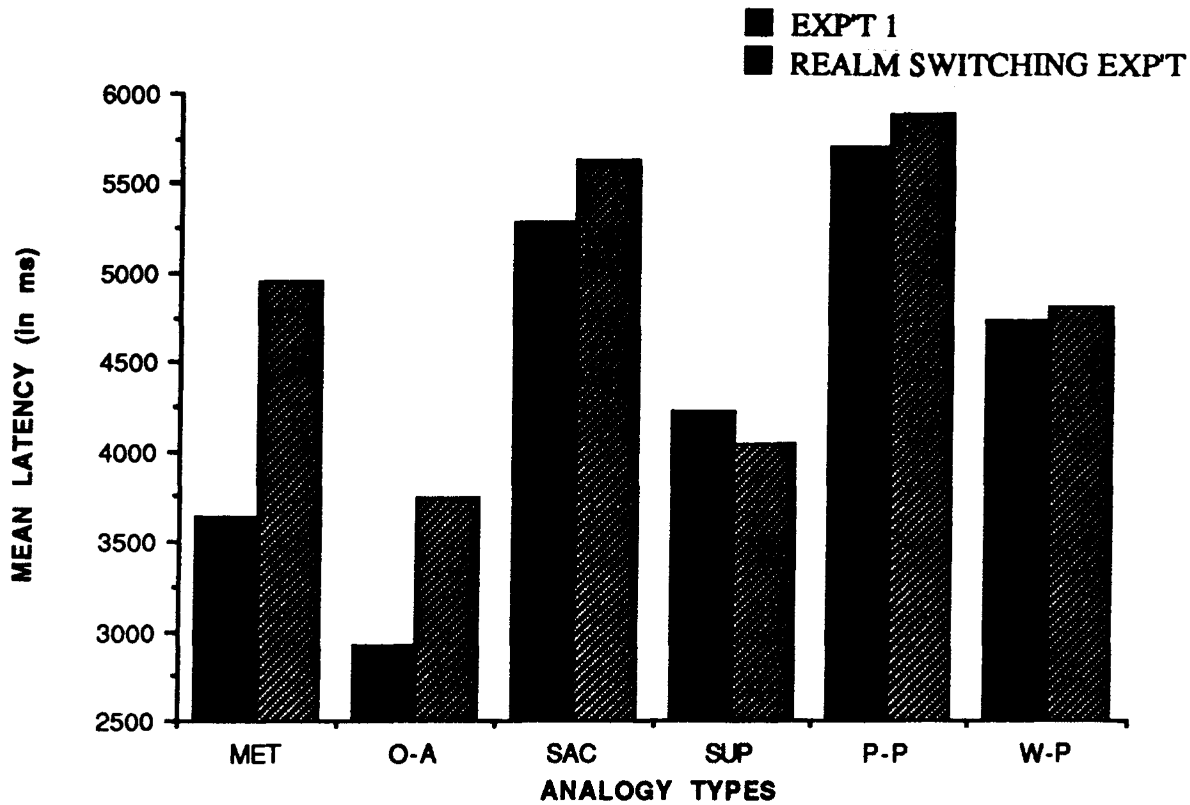
Experiment	Analogy Type		
	Metamorphosis	Same Class	Part-Part
1A (recognition):	3717(185)	4291(290)	4686(312)
5A (recognition):	4726(367)	4357(302)	4972(384)
1B (recall):	3630(229)	5279(326)	5695(372)
5B (recall):	4958(1029)	5620(449)	5878(542)
	Object-action	Super/subord.	Whole-part
1A (recognition):	3286(119)	3603(171)	4109(242)
5A (recognition):	4200(288)	4167(266)	4624(353)
1B (recall):	2919(149)	4225(342)	4736(347)
5B (recall):	3740(403)	4048(225)	4806(479)

notes. standard error values in brackets.
latencies and standard errors are given in milliseconds.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST

Figure 17. Mean solution latencies of recognition data from Experiment 1 and the Realm Switching Experiment.



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST

Figure 18. Mean solution latencies of recall data from Experiment 1 and the Realm Switching Experiment.

effect of realm switching was tested for each of the six analogy types. These tests showed significant latency increases only for metamorphosis, $\underline{F}(1,92) = 6.3$, $\underline{MS_e} = 1937903.9$, and object-action types, $\underline{F}(1,92) = 5.1$, $\underline{MS_e} = 1937903.9$.

In the data from the recall paradigm there was also no main effect of realm switching, $\underline{F} < 1$. As for the recognition paradigm, this factor interacted with the functional/structural dimension, although the effect was marginal, $\underline{F}(2,92) = 2.9$, $\underline{MS_e} = 2624601$, $.1 > \underline{p} > .05$. As in the data from the recognition paradigm, this interaction was caused by the relatively large latency increases for analogy types at the lowest level of the functional/structural dimension. No other interactions with the realm switching manipulation were found ($\underline{F}$ values < 2). In the analysis of simple main effects, only the metamorphosis analogy type showed a significant latency increase with realm switching, $\underline{F}(1,92) = 4.2$, $\underline{MS_e} = 5106435.7$.

Error Data

The error rate in the recognition paradigm was low and virtually equal in the two experiments (i.e. less than 2%). The recall data show a very different pattern. The error rates for this paradigm show an increase from 11% of all responses in Experiment 1 (157 errors), to 19% in this experiment (280 errors). Appendix P lists the total number of errors made by subjects on each analogy type, together with the error rates in Experiment 1.

Discussion

This discussion will address the results separately for analogy types at each level of the functional/structural dimension. First, a short discussion addresses the implications of the insignificant effect of the realm switching manipulation on analogy types from the top two levels. Following this, the latency changes found for metamorphosis and object-action analogy types are addressed.

Lack of Realm Switching Effect on Analogy Types of the Top Two Tiers

Although realm switching produced longer mean solution latencies for most analogy types, for those at the top two tiers of the cube in Figure 1 these increases were not statistically significant. Apparently, subjects were equally successful in realizing the common association between the two word pairs regardless of the similarity of their subject matter. What does this evidence tell us about the relative importance of association types versus word attributes in the process of solving analogy problems generally?

For top tier analogy types, since Experiment 1 demonstrated a specificity effect between problems in which the match of the spatial attributes between the word pairs was manipulated, the failure of the realm switching manipulation may simply indicate that spatial attributes are more critical to the processing of these analogy types. Furthermore, perhaps the ineffectiveness of manipulating taxonomic similarity in these analogy types indicates that only word attributes directly related to the analogy's association type significantly affect solution processing. By this rule, the attributes depicting spatial, physical relationships between objects are related to the structural associations between parts and wholes, and so influence the processing of whole-part and part-part problems. In contrast, taxonomic attributes are not related to these association types, so they do not.

Extending this argument to the context of analogy types on the middle tier, it predicts that the manipulation of taxonomic similarity between word pairs should affect the processing of these types of analogy problems. This is because word attributes defining the taxonomic class of the object depicted is closely related to super/subordinate and same class associations. However, no main effect of realm switching was evident in the latencies of these types of analogies either. On the basis of this experiment then, the suggestion that word attributes affect analogical processing most when they relate directly to the association type in the problem is not supported beyond the data for the top tier analogy types.

However, for analogy types on the middle tier the ineffectiveness of manipulating taxonomic similarity between word pairs raises two possibilities about the relative roles of word attributes and associations in the processing of analogy problems. The first is the possibility that word attributes have an important role in the processing of these analogy types, but that this experiment manipulated the wrong type of word attributes to illustrate this role. For example, it is possible that the spatial attributes responsible for the specificity effect in the top tier analogy types in Experiment 1 might play an important role in the solution process for the middle tier types as well. In future research this role might be demonstrated in super/subordinate or same class problems using words depicting objects with highly salient shape or size attributes, and manipulating the similarity of these attributes between conditions.

An alternate explanation for the ineffectiveness of realm switching on these analogy types is that the processing of super/subordinate and same class analogies are generally immune to the influence of word attributes. This may be true simply because the associations in these problem types are readily represented in abstract form. This idea was proposed earlier in the thesis where it was suggested that these analogy types were susceptible to priming because the associations within them were easily represented by verbal mnemonics such as "(corn) is a type of (vegetable)". If this is true, then during the process of forming a representation of the association appearing in the first word pair, the word attributes will not become part of this representation, and therefore will not be transferred to the second pair. If subjects use this type of association representation, no type of dissimilarity between word pairs could significantly affect the solution times for super/subordinate or same class analogy problems.

Effects of Realm Switching on Analogy Types of the Bottom Tier

The effect of realm switching on metamorphosis and object-action analogies was to increase the solution latencies for these problems by approximately one second. This result shows that, unlike the effect of realm switching on other analogy types, dissimilarities between the word pairs in these problems disrupted the cognitive processes involved in transferring the association between word pairs. This explanation of this result is made especially clear by the fact that the dissimilarity of these attributes in realm switched object-action and metamorphosis problems is so readily apparent. To illustrate, the original metamorphosis problems **plum : prune** as **grape : raisin** and **cow : hamburger** as **pig : bacon** were used to compose the realm switched problem **plum : prune** as **pig : bacon.** The similarity between the attributes associated with metamorphosis in **plum** and **pig** is less apparent than the match of these attributes in **plum** and **grape** or **cow** and **pig**. Furthermore this difference can be easily described: the attributes associated with metamorphosis in **plum** and **grape** depict an object that may be transformed through the process of drying, whereas the metamorphosis relevant attributes in the animals pertain to refining them for consumption through butchering.

A more thorough consideration of these illustrations complicates this issue about the role of word attributes in the solution process. The explanation that realm switching lengthened solution latencies by reducing the match between word attributes ignores the possibility that this effect may have been caused by the use of two different subtypes of an association within each realm switched problem. That is, if the original set of ten metamorphosis analogy problems consist of problems that form psychologically meaningful subcategories, then the construction of new problems for the realm switching experiment was performed by combining word pairs from analogy problems of different subtypes. Thus, a second explanation of the results of this experiment relates to the role of associations in the solution process.

In order to further discuss the distinction between analogy problems with word attributes mismatched between word pairs, and problems with association types mismatched, the reader is again asked to think of associations as procedures of cognitive activity. By this view each association consists of the activation of a characteristic defining its type, and the activation of many other characteristics specifying its nature. If the defining characteristic of metamorphosis associations is represented as [state change] then various metamorphosis associations can be represented as the following sets of activated characteristics:

Association Represented		List of Activated Characteristics Making Up Its Representation
plum : prune	=	[state change] + [drying] + [food] + [fruit] + [part of tree]
grape : raisin	=	[state change] + [drying] + [food] + [fruit] + [part of vine]
cow : hamburger	=	[state change] + [slaughter] + [food] + [ground product]
pig : bacon	=	[state change] + [slaughter] + [food] + [sliced product]

While all the associations represented above are of the metamorphosis type because they have the [state change] characteristic in common, they also vary in their similarity to each other. For example, the associations in the first two word pairs are highly similar because they share many characteristics in common, whereas the second and third associations are less similar because they share few characteristics in common. Given such a continuum of similarity among these metamorphosis associations, what basis should be used for deciding which characteristics distinguish associations as different subtypes? Likewise, how should we decide which characteristics should be regarded merely as a result of different word attributes when they differ between associations of the same subtype?

In answering these questions, we may consider what criteria have been used to claim the discovery of analogy types. The claim that types of analogies have been discovered among the 80 analogy problems used in Experiment 1 is based on the demonstration that problems with a common characteristic (eg. [state change]) show evidence of similar processing. So for example, ten metamorphosis problems have shown characteristic solution latencies which distinguish them from many other types.

Likewise, association subtypes might be inferred to exist among the associations contained by the ten metamorphosis problems, if a group of these problems demonstrates that they are processed similarly. So for example, if a group of problems using associations made up of [state change] and [drying] characteristics elicit similar solution latencies, or are consciously classified as a subgroup, the associations in these problems can be considered a subtype of the metamorphosis type. Conversely, if a characteristic of a word pair does not influence the solution process of analogies similarly in the context of different problems, it can be considered an attribute of the particular words used in these problems. For example, the characteristic [animated object] is included in both object-action and whole-part analogies in my stimulus set, but it was not expected to influence subjects' solution processes similarly in these contexts.

Thus far, the results of this experiment have been used to introduce an issue as to whether realm switched problems were made more difficult by the word attributes mismatched within them, or by the mismatching of their association subtypes. From this issue, an argument can be made that this distinction might be resolved in future research. Suggestions for such future research will be presented in the general discussion chapter of this thesis. Before concluding this chapter, the reader is reminded that the same issues exist among object-action analogies. Some distinctions among object-action problems are so apparent that lexical labels to describe them readily come to mind. For example, some object-action associations are based on objects' sounds (eg. **lion : roar**), others are based on objects' movements (**rabbit : hop**), others pertain to objects' functions or uses (eg. **hammer : pound**). If these differences were confirmed by subjects' solution latencies, and/or by subjects' judgements about the relative similarity of different problems, the claim that psychologically salient subtypes exist within the object-action type would also be empirically supported.

General Discussion of Chapter Eight

The two experiments reported in this chapter were designed to investigate the role of word attributes on the process of solving analogy problems. Experiment 4 replicated the specificity effect found in Experiment 1, even though the same third position words were used in specific and nonspecific problems. This finding shows that the processing advantage for specific problems does not result from the particular words used in these problems, but results instead from the similarity between the two word pairs within a problem. In this experiment, as in Experiment 1, the type of similarity manipulated to produce this specificity effect was the spatial relationship of the objects depicted by the word pairs.

Experiment 5 attempted to show that another type of similarity between these word pairs could be manipulated to increase latencies for problems in which this similarity was low. In this experiment, the similarity of the subject matter addressed by these word pairs was reduced compared to the similarity that appeared between pairs in Experiment 1. For most analogy types latencies did not increase generally enough to support the hypothesis that the taxonomic identity of the words involved was critical to the analogy problem solving process. However, the clear effect of mismatching this type of attribute in the object-action and metamorphosis analogy types raised the theoretical concern that association subtypes may exist within the association types used as the basis for these analogy types.

Together, these experiments provide some insights about the role of word attributes in the processing of analogy problems. In Experiment 3 attributes of the third position words were shown to adversely affect subjects' processing of analogy problems. This role was not examined under controlled conditions, but it probably resulted because these words were misinterpreted, or because they elicited associates irrelevant to the solution. Experiments 4 and 5 demonstrate another role of word attributes, which has been implicated in my theoretical explanation of specificity. This is the role played by word attributes when they match between word pairs. The processing advantage demonstrated for specific problems supports two theoretical points: i) that when the association from the first word pair is transferred to the second pair, its representation is based in part on the attributes of the words initially forming that association, and ii) that this association is most easily recognized in the second pair when these attributes are similar between pairs. Experiment 4 demonstrated this latency lengthening for nonspecific problems under conditions where the particular third word attributes were experimentally controlled between specific and nonspecific conditions. Experiment 5 showed that the similarity of word attributes identifying objects' taxonomic class may also enhance the transfer of the association between word pairs. In demonstrating this however, this experiment raised a theoretical question regarding when the role of these word attributes is influential enough to constitute subdivisions of the association types themselves.

Two methods for identifying association subtypes will be suggested now in order to introduce some of the motivation for the following experiment. First, reports as to the association types that subjects perceive among problems could be derived by having them sort these problems into categories they create. This would allow subjects to express their judgements of similarity without using explicit labels. Second, it might be possible to distinguish the effect of word attributes and the effect of association types on analogy problem solving functionally, according to how explicitly subjects process these two types of information. That is, it is possible that the association type in a problem is consciously attended by subjects in all cases, but that the detailed attributes of the words involved need not be explicitly processed unless their mismatch between word pairs creates a processing disruption. If this is true, when subjects process specific analogies they should be highly aware of the nature of the association type, but not necessarily aware of the word attributes involved.

The following chapter reports on an initial attempt to investigate these ideas using a sorting task. Subjects were asked to sort analogy problems into their own categories, as a test of whether they recognize the association types I proposed in the cube in Figure 1. As well, the results of this sorting task were analyzed to determine if subjects explicitly recognized the difference between analogies where word attributes are closely matched between word pairs (specific types) and those where they are not (nonspecific). If subjects show no recognition of this specificity distinction, it may reflect the relatively implicit processing of word attributes in specific problems.

CHAPTER NINE
EXPERIMENT 6: SORTING TASK

Rationale

The results of previous experiments have differentiated analogy types according to the three dimensions portrayed in Figure 1. These experiments have used problem solving paradigms to demonstrate that different analogy types produce different solution latencies. For example, specificity and inclusiveness have consistently enhanced the speed with which analogy problems are solved. The present experiment was conducted to determine whether corroborative evidence for these same distinctions could be found using a paradigm where subjects consciously attempt to sort analogies into categories. In this task subjects were presented with slips of paper each containing one of the eighty analogies used in previous experiments, and were asked to sort them into categories of their own choice. Subjects were told to use between four and ten categories, but were not given any criteria for forming them, so that their classification schemes were free to confirm or disconfirm the one presented in Figure 1.

This method is similar to one used by Whitely (1977b). She used a set of 60 four word analogies and found that subjects could reliably distinguish eight types by sorting these analogies according to the associations within their word pairs. Of these eight types, four are similar to those on the bottom tier of my typlogy cube: object-action, metamorphosis, same class, and super/subordinate. The other types were identified in the word association literature but excluded from my typology. They are antonyms, similarities, quantitative, and a language related type called word patterns (eg. **ant : owl** as **tan : low**). While Whitely did not record solution latencies and did not demonstrate performance distinctions among her analogy types, her work showed that this sorting task can be used to distinguish analogy types, including some relevant to this thesis.

In the present experiment, four goals were addressed. The most general was to determine whether the categories formed would be consistent across subjects, and if so, whether these categories would resemble the typology shown in Figure 1. A second goal was to determine whether the inclusiveness dimension would appear in subjects' category distinctions. A third was to determine whether the specificity distinction would be demonstrated. This was of particular interest because specificity distinguishes between analogy types constructed from the same type of association, whereas the other two dimensions distinguish between analogy types constructed from different types of associations. The failure of subjects to use the specificity distinction in this sorting task would feed speculation that the word attributes determining the specificity of a problem may require processing qualitatively different from (perhaps less explicit than) the processing of the information distinguishing types of associations.

The final goal was to determine which particular analogy problems were classified in ways contrary to the scheme proposed in this thesis. Testing this goal would only be possible if the analogy types presented in Figure 1 were, in general, validated by the sorting results. This goal was motivated by the question as to whether any individual problems had misrepresented the categories to which I had assigned them.

Method

Stimuli. The same eighty analogies used in Experiment 1 were used in this study. They were printed on slips of paper approximately 1 X 18 cm. Each analogy was printed complete with the solution word appearing in the fourth position.

Procedure. After completing Experiment 5, subjects were taken to a small study room where they were introduced to the sorting task. The instructions told subjects to sort the eighty analogies according to the nature of the relations between the word pairs in each case. Subjects were told to use between four and ten categories for their sort, and were told to include each analogy in one of these categories. The exact, written instructions given to subjects appear in Appendix Q. The eighty slips of paper were then dumped in a pile on a large table. No attempt was made to arrange them or to suggest exemplars with which to begin the sort. Subjects were allowed to work at this task as long as they required. They usually took approximately forty minutes.

When the analogies were sorted, subjects were asked to describe their categories. They were instructed to describe each category in general terms, and to illustrate their explanation with one of the analogies from the category. See Appendix Q for exact written instructions for this task. All subjects were asked to speak these reports into a tape recorder, but two subjects requested to submit hand written reports, and they were allowed to do so. Subjects had little difficulty understanding or performing the task.

Subjects. The same 24 subjects (12 males, 12 females) used in Experiment 4 also participated in this experiment.

Results

The mean number of categories produced by subjects was 7.1. Since this mean is one category fewer than the eight used in the typology in Figure 1, this statistic forewarned the possibility that not all categories would be recognized and distinguished by subjects in this task. Table 15 shows the distribution of the number of categories produced by the 24 subjects. Although the range of this distribution is high (4 to 11 categories were used) there is a great central tendency (standard deviation = 1.65) with 17 out of 24 subjects using between 6 and 8 categories. The variability of the size of these categories was also large. The mean size of subjects' largest categories was 21.7 analogies. The mean size of their smallest categories was only 5.5.

Table 15

Number of Categories Used by Subjects in Sorting Task

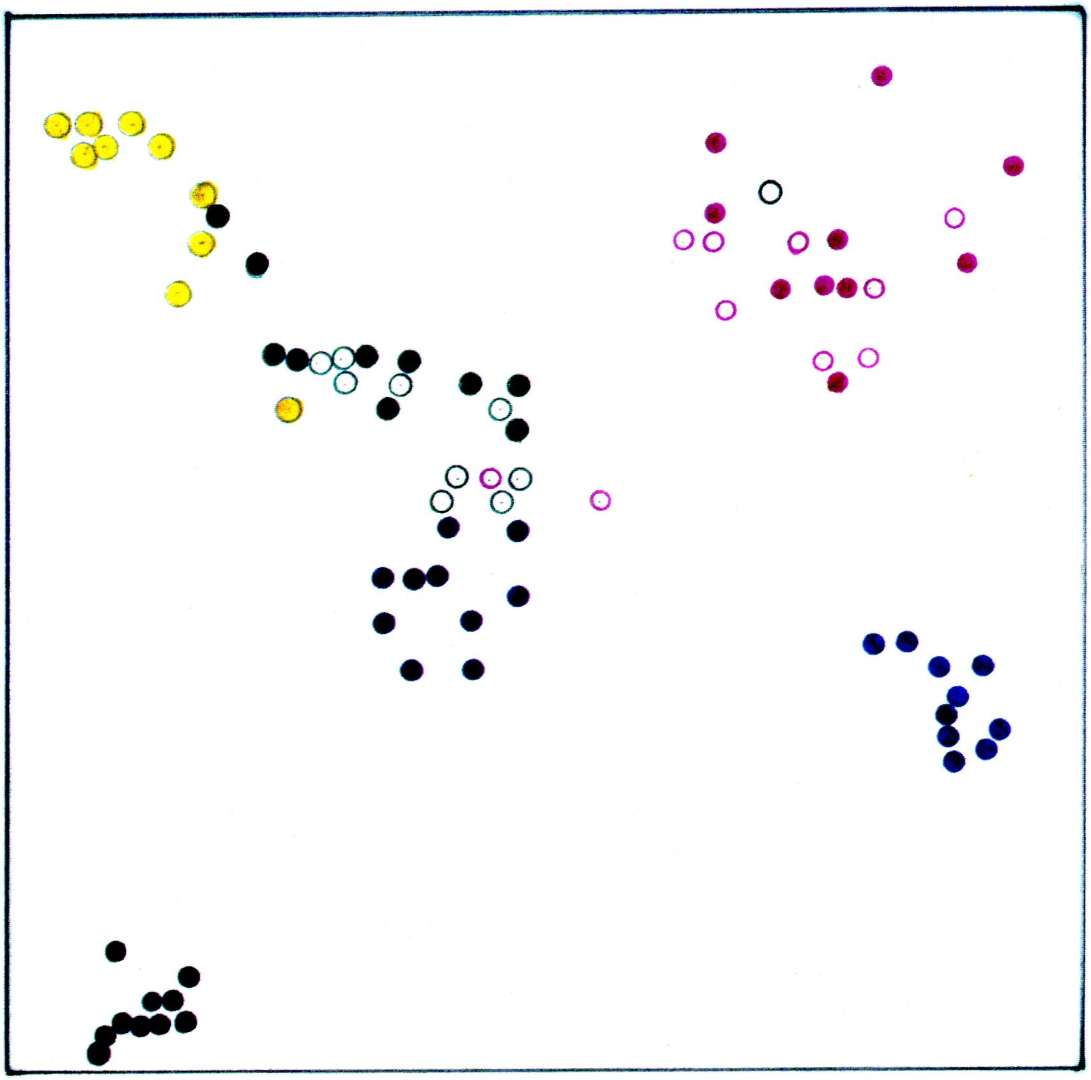
Number of Categories Used by Subjects	4	5	6	7	8	9	10	11
Number of Subjects Using That Number of Categories	2	2	4	6	7	1	1	1

The results of these sorts were scored as similarity judgements between each pair of analogies. Pairs of analogies placed in the same category were given a similarity rating of 1, while pairs placed in different categories were assigned a rating of 0. This scoring system yielded a 79 X 79 triangular matrix for each subject, wherein each cell consists of the similarity score for a pair of analogies. These matrices were combined across the 24 subjects, resulting in a single matrix where each cell consisted of a similarity score ranging from 0 to 24. (The matrix appears in Appendix R.) This matrix was submitted to multidimensional scaling and cluster analysis programs from the Statistical Package for the Social Sciences (1983). Multidimensional scaling was performed on the Alscal program, and cluster analyses were performed on the Cluster program from this package.

Multidimensional Scaling

The multidimensional scaling program produced two-dimensional and three-dimensional plots with stress levels of .214 and .075, respectively. The two dimensional plot appears as Figure 19, the three dimensional plots appear in Appendix S. Although the three dimensional scaling of this similarity data reduced the stress of the model by .139, the information provided by these plots will not be discussed in detail, for two reasons. First, much of the stress removed by this extra dimension is removed because the analogy types most distinguished on the two dimensional plane are further separated on the third dimension. Namely, the super/subordinate analogies are placed high on this third dimension, and the object-action analogies are scaled lower on this dimension than all other analogies. Secondly, the variance accounted for by this third dimension is also addressed by the clustering analysis presented below. In the case of some individual analogies, their similarity to other problems in their category can be clearly portrayed by depicting the results of the cluster analysis. The discussion of these cases will be presented below.

These similarity data were also scaled in four and five dimensions, improving



●	MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
●	O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
●	SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
●	SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
●	P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
○	SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
●	W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
○	SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 19. Two dimensional solution of similarity data from the Sorting Task (Exp't 6).

stress levels to .027 and .013, respectively. These improvements were not considered enough to warrant further consideration here.

Three aspects of the two dimensional plot in Figure 19 are highlighted here for further analysis and discussion. First, six analogy types constructed from different association types (represented by different colours in this figure) are distinguished as separate categories; the problems within each type are located in close proximity to each other and those of different types are separated by greater distances in the two dimensional plane. Secondly, the distance between analogies of different types is particularly well pronounced between inclusive and noninclusive analogy types. Inclusive types (whole-part, super/subordinate and object-action; red, blue and black, respectively, on the figure) form close clusters on the plane, and are situated in distinctly separate areas from the three noninclusive types (part-part, same class and metamorphosis; green, purple and yellow, respectively). Thirdly, the distinction between specific and nonspecific analogies of the part-part and whole-part types is not evident in this figure. In the figure, specific analogies are represented by empty dots, and the nonspecific analogies are represented by filled dots. Neither part-part nor whole-part analogies show separate clusters for empty and filled dots in the two-dimensional plane.

In order to test how well subjects distinguished between analogies of different types, a series of ANOVA were conducted. These ANOVA compared the variability of the positions of the ten analogy problems within each type to the mean differences between analogies of different types. The sum of squares for variance within each analogy type consisted of the squared distances of each problem from its group's mean position. The mean squared error terms derived from these values were pooled across all eight analogy types to yield a single value (.1732) used as the denominator for all tests.

A series of ANOVA were performed, each testing the significance of the mean distances between a pair of analogy types. In all, fourteen ANOVA were performed. These tested whether subjects separated pairs of analogy types distinguished by specificity, those distinguished by inclusiveness and those varying along the functional/structural dimension. These ANOVA are reported in Table 16.

The first two ANOVAs listed clearly show that specific and nonspecific types were not distinguished by subjects for either part-part or whole-part types. The third and fourth of these ANOVA show that, among these same analogy types, inclusive types were distinguished from noninclusive types. The next two (5 & 6) show that this inclusiveness distinction also exists between the other two inclusive types (object-action and super/subordinate) and the noninclusive analogy type located closest to them on the plane (metamorphosis).

The remaining eight analyses all compare pairs of analogy types homogeneous with regard to inclusiveness. ANOVAs 7, 8, and 9 all show the three inclusive groups to be significantly distinct from each other. However, among the noninclusive types the results are not as consistent. While the same class type is distinct from metamorphosis and specific part-part types (ANOVAs 10 & 11), it is only marginally separate from the part-part type (12). For the metamorphosis type, the distance from part-part analogies is also marginal (13), and its separation from specific part-part analogies is not significant (14).

Clustering

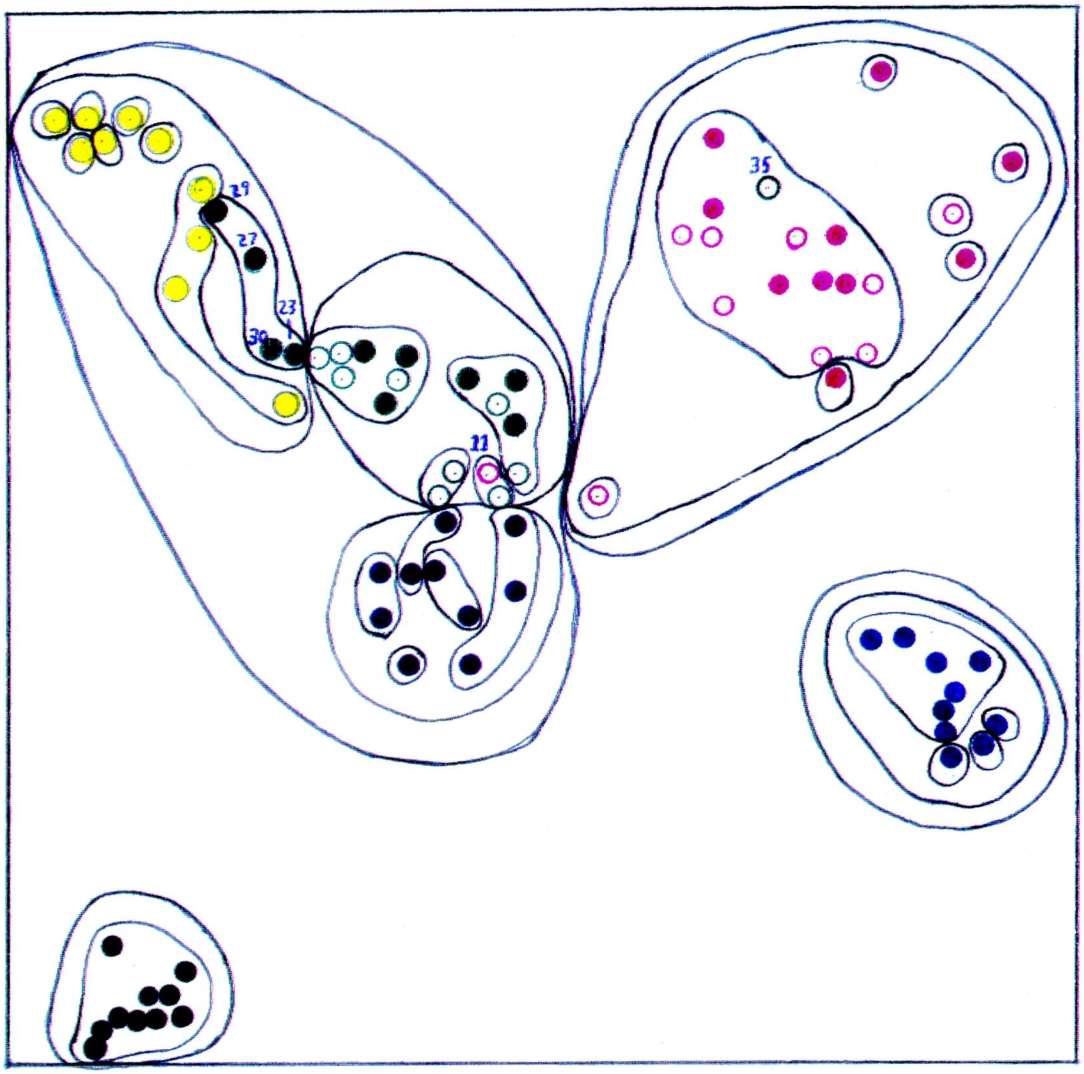
The cluster analysis program was used to generate three analyses using three types of linkage methods: i) the complete, or furthest neighbor linkage, ii) the single, or nearest neighbor linkage, and iii) the average linkage between groups. The analysis based on average linkage yielded the most systematic organization of the stimuli compatible with the typology in the cube in Figure 1, and it was the basis for the cluster contours in Figure 20. The full cluster analysis appears as a dendrogram in Appendix T.

This analysis confirms the observations made of the similarity patterns presented in the two-dimensional scaling analysis. First, the six analogy types

Table 16

Source Table for ANOVAs on Two-Dimensional Clusters from the Sorting Task Similarity Data

	Comparison	MS	$F(1,72)$	p
1.	W-P vs SW-P	.190	1.10	>.1
2.	P-P vs SP-P	.128	.74	>.1
3.	P-P vs W-P	2.95	17.02	<.01
4.	SP-P vs SW-P	1.73	10.00	<.01
5.	MET vs SUPS	3.25	18.76	<.01
6.	MET vs SUPS	3.32	19.17	<.01
7.	SUPS vs W-P	2.86	16.51	<.01
8.	SUPS vs SW-P	2.29	13.22	<.01
9.	SUPS vs O-A	9.30	53.69	<.01
10.	MET vs SACL	3.11	17.96	<.01
11.	SP-P vs SACL	1.73	10.00	<.01
12.	P-P vs SACL	.93	5.35	<.05
13.	P-P vs MET	.80	4.60	<.05
14.	SP-P vs MET	.49	2.85	>.05
	Error	.17		



MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Figure 20. Two dimensional solution of similarity data from the Sorting Task, with cluster contours.

forming the front face of the typology cube in Figure 1 form separate and distinct clusters. Secondly, the inclusiveness distinction is evident in the clusters, since the four noninclusive types were clustered together before any of the inclusive clusters were included. This indicates that subjects discovered the common noninclusive characteristic among these four types, and used it as a basis for their sorting decisions. Thirdly, since specific and nonspecific problems are clustered together at all levels of analysis, little evidence exists to suggest that subjects recognized specific analogies as a separate group from nonspecific analogies, within either the part-part or the whole-part clusters.

The cluster contours illustrated in Figure 20 also show that for some individual stimuli, similarity judgements are contrary to the categories they were assigned to in earlier experiments. In some cases this confirms the impression presented by the two dimensional plot of these data, but in other cases the cluster analysis provides clarification of subjects' similarity judgements which are also evident in the three dimensional scaling results (see Appendix S). Two analogy problems are deviants according to all analyses. They are case 35, a specific part-part analogy clustered with whole-part analogies, and case 11, a specific whole-part analogy clustered with part-part analogies. These cases are marked on Figure 20, and are clearly the most deviant members of their respective categories. Table 17 lists these analogies, identifies them by case number, and indicates their type according to the original classification, and the cluster with which subjects identified them.

Two other analogies appear to be deviant problems on the two dimensional plot, but are clustered as members of their category. First, case 20, a specific whole-part analogy is plotted close to the part-part analogies in the two-dimensional plot, but is clustered in Figure 20 with the whole-part group. Similarly, case 42, a same class analogy plotted near the part-part group, is also clustered according to its type. In both cases, the three dimensional representation of this similarity data confirms this clustering. Finally, the inclusion of four

Table 17

Misclustered Items in the Sorting Task Similarity Data

Case #	Analogy	Type	Clustered Type
11	pool cue : chalk as ski : wax	sp. part-part	whole-part
35	helmet : visor as eye : lid	sp. whole-part	part-part
23	knife : fork as saucer : plate	part-part	same class
27	toilet : tub as stove : fridge	part-part	same class
29	ear : eye as stomach : kidney	part-part	same class
30	balance beam : trampoline as swingset : slide	part-part	same class

part-part analogies (cases 23, 27, 29, and 30) in the same class cluster is also explained by their position in the third dimension of the scaling solution. These problems are all located high in this third dimension, and were clustered accordingly: with the same class analogies. These four cases are also described in Table 17.

Discussion

The most general goal of this experiment was successfully met. Most of the analogy types distinguished by the cube in Figure 1 were also distinguished by subjects' sorting behaviour. Exceptions to this are informative however, and lead to insights about each of the three dimensions of this cube. The relationship between analogies of different types will now be discussed in the context of each of the three analogy dimensions, in turn. Processing implications will also be drawn by comparing these results with the latency patterns of Experiment 1. Finally, individual exceptional problems will be discussed.

Inclusiveness

The inclusiveness distinction was clearly recognized by subjects performing the sorting task. All differences on the two-dimensional plane between inclusive and noninclusive analogy types were statistically significant according to the ANOVAs reported in Table 16. Among the noninclusive analogy types however, the results of the sorting task suggest that subjects had difficulty sorting problems according to their types. Part-part problems were particularly prone to being categorized with metamorphosis, or with same class problems. In contrast, analogies from the inclusive types were very well discriminated from each other.

These results confirm conclusions drawn from earlier problem solving experiments, that inclusiveness plays an important role in determining how subjects process analogies. In addition, these sorting data indicate that inclusiveness is a highly salient characteristic which subjects can readily identify at a conscious level. In fact, the lack of clear discrimination among noninclusive types suggests that the noninclusiveness of these problems is more readily recognized in this task than other characteristics distinguishing these types from each other.

Specificity

The specificity distinction was clearly not made by subjects performing this task. Neither of the two ANOVAs comparing specific and nonspecific analogy types within either whole-part or part-part types showed a reliable difference between them. Subjects failure to distinguish specificity is important because it suggests that the processing of specificity and inclusiveness operate according to different cognitive processes. Whereas inclusiveness showed a clear effect on problem solving and subjects' deliberate sorting of the problems, specificity influenced solution times only in the problem solving experiments. Three possible explanations of the specificity result in this sorting task are offered here.

The first explains that specificity had no effect on sorting behaviour because the subjects in this experiment didn't process the information about the similarities between word pairs. It was possible, in fact, for subjects to perform this task without even reading the second word pair in each analogy. If this explanation is valid, then the degree of matching of the attributes between word pairs had little effect on sorting simply because it becomes apparent so much later in the processing system than do the cues pertaining to inclusiveness.

The second explanation states that subjects did read the full analogies, and did process the relationship between them, but failed to recognize its relevance in the sorting task. By this explanation, subjects' recognition of similarity or dissimilarity between word pairs is just as explicit as their processing of information regarding inclusiveness, but subjects also consciously decided that this information was irrelevant to the task.

Thirdly, this result may have occurred because subjects processed the analogies fully, but failed to use specificity as a sorting criteria because this information is not available on a conscious, explicit level. That is, perhaps subjects don't process this information explicitly. If this is true it supports my procedural model of processing for specificity which states that for specific problems information about the first word pair is automatically applied to the second pair without the effortful deliberation typical for nonspecific problems.

Future research could distinguish between these possible explanations and resolve the issue regarding the processing differences between specific and nonspecific problems. For example, if subjects were offered my eighty analogies in problem form where they generated the solution word prior to categorizing the analogy, they would be forced to process both word pairs, and to attend to the information in common between them. In this case, if specific and nonspecific analogies continued to be grouped together, the first explanation above would be discredited. Secondly, if subjects were forced to form subcategories among the specific and nonspecific analogies grouped together within whole-part or part-part clusters, they would inevitably resort to whatever information they had available to make these further distinctions. If this method did not reveal the specificity distinction among these subsequent classifications, it would validate the last explanation, not the second one.

The Functional/structural Dimension

Four observations are notable among the clustering results for analogy types varying on this dimension. The first pertains to distinctions among analogy types from the three levels of the functional/structural dimension. Whereas these distinctions are clear among the inclusive analogy types, they are less clear for the noninclusive types. This may have an interesting processing implication. Subjects apparently did not recognize inclusiveness as a commonality among inclusive types; instead their processing resources were apparently consumed by the differences between these inclusive types. In contrast, an analogy's noninclusiveness is apparently less easily overlooked when making similarity judgements; it was used as a basis for classifying these noninclusive types together in spite of other characteristics distinguishing them from each other.

Secondly, the ANOVA performed on these data showed that the similarity among noninclusive analogy types was strongest between metamorphosis and specific part-part types, since the difference between these clusters was not statistically significant. This perceived similarity between types is of particular interest since the similarity between word pairs in metamorphosis problems does not pertain to physical, spatial relationship between objects, as it does in specific analogies.

The third notable result is that the ten object-action analogies formed a highly cohesive cluster which was well separated from the other seventy analogies. This is of particular interest in light of the discussion in the previous chapter which suggested that the ten problems of this analogy type might be heterogeneous with regard to associations used, or the attributes of the words forming these associations. These two conclusions are not entirely incompatible, however. The difference between this analogy type and others may be highly salient, even though the ten problems of this type comprise salient subgroups.

Finally, the four analogy types on the two lower levels of the functional/structural dimension are clearly distinguished. This provides particularly clear confirmation of these analogy types as distinct from each other, particularly in light of Whitely's (1977b) work which showed a very similar finding.

Exceptional Analogies

The taxonomy of analogy types appearing in Figure 1 is further confirmed by the individual problems inconsistently classified in the sorting task. This is because the problems clustered outside their originally assigned category bear a resemblance to the category with which they were clustered. (This information is listed in Table 17.) To illustrate, case 11, **pool cue : chalk** as **ski : wax** was clustered as a part-part analogy, and case 35, **helmet : visor as eye : lid**, was clustered as a whole-part item. In both cases the concept identified by the first word pair can be interpreted as whole object containing the second (as in a whole-part association), or as a part of another whole object (as in a part-part association). In both case 11 and case 35 subjects tended to regard the problem differently than the original classification. But, in both cases they did so in a way that is understandable, and is compatible with the other problems placed in the categories subjects used.

Likewise, the four part-part analogies that were clustered as same class analogies illustrate the conceptual fuzziness of the boundary between these types. For example, **knife** and **fork** can be interpreted as parts of a place setting or as members of the kitchen implements category. This is because the objects referred to are not physically connected to each other within a whole object, but instead form collections of objects frequently regarded as parts of a larger entity (place setting). Again, the misclustering of these problems is sensible, and indirectly confirms the validity of the categories.

Finally, a comparison should be made between these exceptional analogies and those identified in Experiments 1 and 2 as outliers and inconsistent analogies. Three of the analogies listed in Table 17 were also identified as exceptional in earlier experiments. Case 11 elicited exceptionally long latencies in Experiment 1. Since this long latency is consistent with the latencies of the part-part analogies it was clustered with, the results of the two experiments provide converging evidence that this analogy is viewed as a part-part analogy. Likewise, case 23 had exceptionally short latencies compared to other analogies of its assigned part-part type. This deviance was also consistent with the analogies of the same class type with which it was clustered, and so supports this interpretation of its identity. Finally, while case 35 yielded long latencies in Experiment 2, this occurred in the recognition paradigm only, and does not coincide with its clustered classification (same class analogies are more quickly solved). As a result no conclusions will be made from this example.

In general the classification of these exceptional problems is understandable, and is consistent with the view that these clusters formed categories corresponding to my typology. In short, these exceptional problems are not typical exemplars of the categories to which they were assigned, but they do not threaten the validity of the analogy types proposed.

Summary

The results of the sorting task confirmed many of the findings discovered in the problem solving paradigms used earlier in this thesis. The cohesiveness of analogy types was clearly demonstrated. The distinctions between inclusive and noninclusive analogies was also confirmed, as were the distinctions among the levels of the functional/structural dimension, in most cases. The distinction between specific and nonspecific analogies was not evident in the results of the sorting task, however. This indicates that different types of cognitive activities must be held accountable for specificity and inclusiveness distinctions.

CHAPTER TEN: GENERAL DISCUSSION

This chapter has six sections. The first reviews the major goals and hypotheses that motivated my research. The second section summarizes the main findings that emerged from the experiments reported in Chapters 4 to 9. The third section explores some implications of these findings, and it relates them to more general theoretical issues that were reviewed in Chapter 3. The next section lists several factors that limit the generality of the findings, and the following section outlines future research that would deal with these limitations. Finally, the chapter ends with a brief summary of the main contributions of the thesis.

Main Goals and Hypotheses

My thesis had three major goals: (i) to search for similarities and differences in subjects' ability to solve different types of analogy problems, (ii) to identify the role of associations (between words) versus the attributes of individual words in solving analogy problems, and (iii) to examine whether the similarities and differences observed when solving analogy problems would also show up in a task that required subjects to categorize analogy problems. An additional but different type of goal was to demonstrate that recall and recognition paradigms are effective tools for investigating the processes involved in solving four word analogy problems. This section outlines these goals in more detail and it describes the hypotheses related to each goal.

Similarities and Differences in Subjects Ability to Solve Different Types of Analogy Problems

Are the same processes or different processes involved in solving different types of analogy problems? This question was motivated by previous research in two areas. First, the analogy problem solving work of Gentner (1983), Holyoak (1985) and Keane (1988) has shown that both the relationships between objects and the specific characteristics of these objects influence subjects' abilities to solve problems by drawing analogies. Thus, it seemed plausible that relationships and word attributes could both be manipulated to illustrate different types of analogies which would elicit distinct patterns of cognitive processing. Secondly, previous research and theory about semantic memory and word associations showed that different types of relationships between concepts had been identified which could easily be tested within the context of four word analogy problems.

Three important hypotheses were formed to address this main goal of demonstrating processing differences for different analogy types. These concern the three dimensions proposed in my typology of analogy types; specificity, inclusiveness, and the functional/structural dimension. The specificity dimension distinguishes specific analogies which use very similar pairs of words within problems, from nonspecific problems which use less similarly matched word pairs. The hypothesis relevant to this dimension states that problems with more similar word pairs should be more quickly solved. The second dimension, inclusiveness, refers to the nature of the association between words within a pair. Some word pairs such as **hull : mast** are mediated through an additional word (i.e. **boat**), whereas other associations are more immediate, as in the pair **boat : mast**. It was hypothesized that noninclusive (mediated) associations would form analogies which produced longer solution times than inclusive, immediate ones. The third, functional/structural dimension provided a preliminary test of a tentative hypothesis that analogy problems based on functional relationships (object-action and metamorphosis) would be more quickly solved than those based on taxonomic relationships (super/subordinate and same class), which in turn would be more quickly solved than those based on structural relationships (whole-part and part-part). This hypothesis was developed from speculation that the types of semantic relationships first used by children early in life (such as functional types) become more practiced throughout development, and should therefore show a corresponding processing advantage in the problem solving behaviour of adults.

Determining the Influence of Associations Versus Word Attributes in Subjects Solution Latencies

The second major goal emerged indirectly from the first. The types of analogy problems used for these experiments differed on the basis of the associations between words (eg. part-whole, super/subordinate), and on the basis of the similarity of the word pairs in each problem. Much of the empirical research in this thesis was conducted to isolate the relative contribution of these two influences on subjects' solution times for four word analogy problems: the influence of the association type in the problem, versus the influence of the attributes of the particular words in the problem.

My research used two methods to examine how associations influence subjects' ability to solve analogy problems. The first is based on the idea that a major portion of the time required to solve an analogy problem stems from processing related to finding, identifying, and activating the association that defines each problem. By this assumption, one might expect that when presented with a series of the same type of problems, association-specific processing would be primed or facilitated. This reasoning lead to the hypothesis that subjects would be faster at solving four word analogy problems when presented with a series of problems of the same type, than when problems are of different types. This hypothesis was examined in Experiment 2. Experiment 3 attempted to study the time required to use different association types by reordering the words within the analogies used in earlier experiments. In some cases, this manipulation changed the nature of the association. Since these new problems were constructed using the same words as in the original problems, this manipulation provided a test of how much these solution times would be affected by the manipulation of the association type only.

Attempts to isolate the influence of word attributes on analogy solution times were complicated because two types of word attribute influences were postulated: i) the tendency of a word to elicit particular associates, and ii) the similarity of the words between pairs. Experiment 4 addressed the possibility that the specificity effect found in Experiment 1 resulted because the particular third words of specific problems were coincidently associated with solution words, and so elicited them more quickly than did the words in nonspecific problems. In Experiment 4 the same third position words were used in both specific and nonspecific problems. It was hypothesized that the specificity effect would still be evident in these problems because the degree of similarity between word pairs in specific and nonspecific conditions was not controlled. Experiment 5 addressed the influence of word similarity between word pairs by manipulating a different aspect of this similarity. The specificity manipulation in earlier experiments was performed by varying the similarity of the spatial relations between objects depicted in each word pair. In contrast, this experiment varied the taxonomic similarity of word pairs within problems, and tested the hypothesis that solution times would be longer for problems in which this similarity was reduced.

Testing Analogy Distinctions in a Sorting Task

A third goal centered on an attempt to determine whether the distinctions among analogy types demonstrated by solution latencies would also be evident when subjects performed a deliberate categorization of these analogies. A sorting task which generated subjects' explicit classifications of these analogies tested hypotheses about specificity, inclusiveness, and the functional/structural dimension.

Testing Two Experimental Paradigms

Another central goal of this thesis was to demonstrate the utility of the recall and recognition paradigms to address the goals discussed above, by showing that they produce similar patterns of solution latencies. An initial hypothesis was that latencies from the recall paradigm would be consistently longer than those of the recognition paradigm, for all analogy types.

Findings

Distinctions Demonstrated on Three Dimensions of Analogy Types

The general goal of demonstrating different cognitive processes for different analogy types was successfully met by the solution latencies yielded by these analogy types. Differences between types occurred on each of the three analogy dimensions identified earlier. In Experiment 1 the data from both paradigms showed that inclusive analogy types produced shorter solution times than noninclusive types, and that specific analogies were solved faster than nonspecific ones. These effects also appeared in the error patterns of Experiment 1. Latencies for the analogy types varying along the functional/structural dimension also differed significantly; mean latencies were ordered as depicted in the vertical dimension of the typology cube in Figure 1. These differences between analogy types, particularly on the specificity and inclusiveness dimensions, were found among solution latencies in several other experiments as well.

Results of Priming and Reordering Analogies

Attempts to isolate the role of association types in the problem solving process were made in Experiments 2 and 3. The priming manipulation in Experiment 2 showed no overall main effect, but small latency decreases did appear for some analogy types. Priming was evident in the three noninclusive, nonspecific analogy types (same class, part-part and metamorphosis), and for the super/subordinate analogy problems.

The reordering manipulation in Experiment 3 increased the time required to solve most types of analogy problems. This increase occurred even for the analogies constructed from part-part associations and for the two specific analogy types, which were not expected to be influenced by reordering. Among the few exceptions to this general increase were the latencies of super/subordinate problems, and whole-part problems in the recall paradigm (which became sub/superordinate and part-whole types after reordering, respectively). Latencies for these types remained unchanged, contrary to the latency decrease expected to result from the greater directiveness of the associations within them. However, perhaps the most striking result of this experiment was the inconsistent effect of reordering on solutions to nonspecific whole-part analogies (which became specific part-whole analogies). In the recognition paradigm a very large latency increase resulted (1222 ms), but in the recall paradigm this increase was minimal (107 ms).

Effects of Manipulating Word Pair Similarity

The role of word attributes was demonstrated in Experiments 4 and 5 by showing that the degree of this similarity between word pairs influenced solution latencies. Experiment 4 showed that nonspecific analogies (for which this similarity between word pairs was low) elicited longer latencies than specific problems, even though the same third position words were used in both conditions. That is, the specificity effect was again demonstrated as faster solution times for problems composed of similar word pairs, this time with the nature of the third position words controlled between specific and nonspecific conditions.

In Experiment 5 reducing the taxonomic similarity between word pairs did not increase latencies for most analogy types. However, metamorphosis and object-action problems did show increased solution latencies for realm switched problems, indicating that this type of similarity enhances the solutions of problems, as did the similarity of spatial attributes manipulated in earlier demonstrations of specificity.

Sorting Results

In the sorting task of Experiment 6 most distinctions among the eight analogy types used in this thesis were recognized by subjects. The clusters of analogies created by subjects in this task showed distinctions between all inclusive and noninclusive types, but that subjects did not group specific analogies separately from nonspecific ones, for either part-part or whole-part types. Thus, the information cuing subjects about the specificity of a problem was apparently not recognized by subjects attending to analogy types in this task.

Results From the Two Paradigms

In general, the most important finding regarding the two paradigms was that similar results were yielded by them in almost all experimental conditions, providing consistent evidence about the hypotheses tested. While subjects required more time to solve some analogy types in the recall paradigm than the recognition paradigm (eg. part-part and same class types), this effect was not general across types. Rather, latencies interacted between paradigms and specificity, and between paradigms and inclusiveness. These interactions showed that more difficult analogy types (i.e. nonspecific and noninclusive types) required the most additional processing time in the recall paradigm.

Implications

Implications of Analogy Dimensions for Problem Solving Research

The time required to solve analogy problems showed an influence of specificity, inclusiveness, and the functional/structural dimensions. This suggests that different cognitive processes are at work when solving these different types of analogies. The implications of this finding for the general study of problem solving by analogy are considerable, largely because the characteristics of these problems that distinguish analogy types in this thesis are also identifiable in other analogy problem contexts. That is, different association types, and different degrees of similarities between vehicle and target domains, are also evident in Dunker's problems for example. It is likely then, that our understanding of the different cognitive processes involved in solving these types of problems will find application in other problem solving contexts as well.

The confirmation of each of the three hypotheses proposed (for inclusiveness, specificity, and functional/structural dimensions) has particular implications for my model of four word analogy processing, which also impact on other research in the field of analogy problem solving. The processing advantage found for inclusive analogies indicates that extra processing time is consumed by the extra inference required to form noninclusive associations. According to the processing model I have proposed, this extra processing occurs at inference and/or application components, where the association is initially formed and then reconstructed, respectively. Because this distinction is essentially based on different association types, this finding is of consequence to theories of analogy problem solving like Gentner's (1983) which explain the difficulty of analogy problems as the difficulty of identifying and transferring the structure of the relationships among the objects, between two domains.

The relatively fast latencies demonstrated for specific problems confirms the hypothesis that a great degree of similarity between word pairs expedites the transfer of the association in the first word pair to the second pair. The procedural explanation of this result states that specificity induces an efficient short-cut in the processing system, expediting processing at the later components of the model. This finding that the semantic attributes of the concepts in the two domains have a role in the problem solving process supports Keane's (1988) view of analogical transfer, which emphasizes the importance of similar details in the procedural transfer of solutions.

Solution latencies were progressively faster for analogy types on the lower tiers of the functional/structural dimension. This finding supports the notion that analogy problems that are more familiar, or more often used, result in shorter processing time. This familiarity factor may correlate with the developmental onset of the ability to use these types of associations. This influence is assumed to occur at early components of my processing model where less familiar association types require the system to spend a longer amount of time discovering the nature of the association in the first word pair. If the familiarity of different types of associations has an influence on solution processing at this critical point in the process, it could affect problem solving behaviour in more practical contexts, since these different associations also appear in Dunker's problems, for example.

The potential for using these findings about inclusiveness and structural/functional dimensions to increase our understanding of subjects' analogical solutions to more practical problems is easily illustrated through the Lightbulb and the Radiation problems presented in Table 18. At the bottom of this table a series of four word analogy problems are listed which have been created from the content of these two stories. The first two of these (A and B) illustrate an inclusive and noninclusive analogy, respectively. The third (problem C) illustrates an object-action problem representing the lowest level of the functional/structural dimension, in contrast to problems A and B which represent the highest level. According to the findings of this thesis, solving the Lightbulb and the Radiation problems will be more difficult if their solutions require subjects to use the more difficult types of these relationships, such as the part-part relationship depicted in problem B.

The role of specificity on the solutions to Dunker type problems has been

Table 18

Four Word Analogies Constructed From The Lightbulb and The Radiation Problems

The Lightbulb Problem

In a physics lab at a major university, Ruth was a research assistant responsible for operating a very sensitive lightbulb. One morning she came into the lab and found that the light bulb over-heated and the filament inside the bulb had broken into two parts. The surrounding glass bulb was completely sealed, so there was no way to open it. Ruth knew the lightbulb could be repaired if a brief, high-intensity laser beam could be used to fuse the two parts of the filament into one. Furthermore, the lab had the necessary equipment to do the job. However, a high intensity laser beam would also break the glass surrounding the filament. At lower intensities the laser would not break the glass, but neither would it fuse the filament.

Solution to The Lightbulb Problem

Ruth placed several lasers in a circle around the lightbulb, and administered low-intensity laser beams from several directions at once. The beams all converged on the filament, where their combined effect was enough to fuse it. Since each spot on the surrounding glass received only a low-intensity beam from one laser, the glass was left intact.
(from Holyoak and Koh, 1987, p.p. 339-40)

The Radiation Problem

Suppose a patient has an inoperable stomach tumor. There are certain rays which can destroy this tumor if their intensity is large enough. At this intensity, however, the rays will also destroy the healthy tissue which surrounds the tumor (e.g., the stomach walls, the abdominal muscles, and so on). How can one destroy the tumor without damaging the healthy tissue through which the rays must travel on their way?

Table 18 (con't)

Solution to The Radiation Problem
Several weak rays are sent from various points outside so they will meet at the tumor site. There the radiation of the rays will be intense, for all the effects will summate at this point. But since they are individually weak, the rays will not damage the healthy tissue that surrounds the tumor.
(Dunker, 1945, as cited in Gleitman, 1986, p. 271)

Four Word Analogies Constructed From The Lightbulb and The Radiation Problems

A	lightbulb : filament as patient : tumour	(whole-part)
B	delicate glass : filament as healthy tissue : tumour	(part-part)
C	laser beam : repair as X-ray : destroy	(object-action)
D	Ruth : delicate glass as doctor : healthy tissue	noninclusive +
E	Ruth : laser as doctor : X-rays	
F	laser : delicate glass as X-rays : healthy tissue	

previously demonstrated by Holyoak and Koh (1987) and Keane (1988). In these works, increasing the similarity between problems was shown to result in more successful solutions to problems derived from the Lightbulb and the Radiation problems in Table 18.

The Influences of Associations Versus Word Attributes in Word Analogies

Attempts to isolate the effects of association types. The results of Experiments 2 and 3 provided little direct evidence that the influence of associations in solving four word analogy problems can be isolated from the influence of word attributes. In Experiment 2 priming reduced solution latencies for noninclusive, nonspecific types and the super/subordinate type, but this effect was modest. The fact that most analogy types did not show priming probably indicates that the processing component responsible for discovering the association in the first word pair (the inference component) processes distracting details of word attributes in problems as well as the association type itself. An alternate explanation of this result would suggest that different analogy types do not require different amounts of processing time in the inference component. By this view, differences in total processing time across analogy types must be located in the later processing components. Further experimental conditions must be run in order to determine whether priming in Experiment 2 was weak because these word attributes prevented subjects from realizing the commonalities between problems, or whether the time savings induced by priming subjects' cognitive system about the association types in problems would not significantly alter solution times in any case. The modest evidence of priming for problems of noninclusive analogy types suggests that the noninclusiveness of an analogy is relatively salient, since this information was recognized by subjects as being common in the ten problems of a block. The modest priming of super/subordinate analogies probably indicates that super/subordinate associations lend themselves to very easy encoding in abstract mnemonics such as "(corn) is a type of (vegetable)", since this information was also transferred among problems within a block.

The general trend toward latency increases for reordered analogies in Experiment 3 can also be accounted for by the processing of word attributes; the associations elicited by the third position words may have distracted subjects from the relevant solution associates. Like the results of Experiment 2 however, this experiment leaves open the real possibility that further experimentation will successfully isolate the role of association types. It is possible that reordered part-whole and sub/superordinate problems (i.e. whole-part and sub/superordinate types) resisted the latency increases found for other reordered problems because the greater directiveness of the associations in these reordered types enhanced their processing.

Attempts to isolate the role of word attributes. The role of word attributes on solution processing was clarified to some degree by the results of Experiments 4 and 5. Experiment 4 showed a specificity effect using problems altered to control the third position words. This indicates that the processing advantage for specific analogies results from the match of attributes between word pairs, not the tendency of the particular words in these problems to elicit solution appropriate associates.

Experiment 5 showed that, for some analogy types, switching realms between the word pairs within an analogy has a similar effect to that of mismatching the spatial attributes of these words, as was done to create the specificity effect in Experiments 1 and 4. The longer processing times for realm switched metamorphosis and object-action types further supported the procedural explanation of specificity. This explanation states that the similarity of attributes between word pairs (i.e. specificity) leads to the transfer of a detailed association between them, thereby reducing the number of solution alternatives (the propositional fan) that must be searched to complete the problem.

Testing analogy distinctions in sorting behavior. The sorting results of Experiment 6 showed that subjects discriminated most problem types except those distinguished by specificity. Since the sorting task engaged subjects in a deliberate categorization activity, this finding suggests that the processing of the cues distinguishing analogies on the other two dimensions is more deliberate than the processing of specificity cues. This conclusion conforms with my theoretical model which proposes that the processing of specificity occurs at a later point in the solution process than the processing of cues regarding the functional/structural dimension or inclusiveness, and occurs more automatically as well.

Although further research must be conducted before firm conclusions can be made about this processing difference, this findings has many potential implications for the study of problem solving generally. It suggests that the type of processing subjects perform depends on their motives for processing an analogy. When subjects in problem solving experiments must transfer information between domains, they engaged a cognitive procedure that leads them to represent the details of the relationship present in the word pairs. In contrast, when subjects in Experiment 6 were required to perform a deliberate classification of these relationships, they apparently focus their processing on different information. This leads to a prediction that students of a particular subject matter who are engaged in the act of discovering problem solutions will represent problems in a more procedural manner than students who study a problem as a particular type.

This processing difference may in turn have implications for how readily these different types of information can be retrieved. For example, the more thorough processing undertaken by subjects who use the problem may lead them to such an instance-related representation of it that they will generate that solution only when faced with very similar problems. In contrast, subjects who merely study the problem, and so represent it in a more general form, may be less automatic in their recognition of its application to a very similar problem, but may be more able to summon its general structure when they deliberately search their memories for problems with similar abstract schema.

Limitations

Limitations of my work are discussed in four areas: i) the stimuli used, ii) the characteristics of the subjects, iii) the limited experimental conditions investigated, and iv) the limited extent to which theoretical claims have been empirically supported. The implications of these limitations on the generality of my findings are outlined as each of these four areas are described in turn. Future research that might help to overcome these limitations will be presented in the next section.

Limitations Regarding Stimuli

Two aspects of my stimuli limit the generalizations that can be made from my findings: i) the vocabulary level of the words used, and ii) the limited number of analogy types tested. The analogy problems used as the stimuli for my experiments consisted of words chosen to tap a grade eight vocabulary level. It is therefore possible that the relative difficulty of these analogy types might change if they were constructed using more sophisticated or technical vocabulary. This is not expected to represent a significant limitation on the generality of the results. Simple words were used intentionally so that word comprehension would not influence subjects' solution latencies.

Secondly, this research used only eight analogy types. While the types used have clearly demonstrated the three dimensions of the cube in Figure 1, further questions might be answered by expanding upon this set. For example, the question of whether the other corner points of the cube might be illustrated by four word problems is one of these. Another is the question of whether subtypes of analogies exist within some of the types used. Other analogy types identified in the word association research and distinguished by Whitely's (1977b) subjects in a sorting task include object-purpose (**coat : wear** as **sandwich : eat**) and sequencing (**dime : penny** as **decade : year**). These may serve as a basis for addressing future research questions such as: Are object-purpose analogies a subcategory of the object-action type? Can specific and nonspecific types of sequencing analogies be constructed? Do other dimensions exist? The limitations addressed by these questions pertain primarily to the theoretical basis of the dimensions in the typology of Figure 1.

Limitations Regarding Subjects

All subjects were young adult university students. Both their age and the education levels might potentially restrict the generality of my results. The highly academic background of my subjects may have influenced their solution latencies in at least two ways. One concerns the possibility that the ability to solve analogy problems based on different association types may be influenced by education. For example, the relative speed with which these subjects use class oriented associations, such as super/subordinate and same class types, may be a product of educational experiences that emphasize these types of associations. Secondly, the academic background of the subjects may have enhanced their general inferential abilities. If it can be argued that North American schools coach students in the skill of inferential thinking, then less educated subjects might show greater difficulty in solving problems that require inferential thinking, such as noninclusive types.

My subjects' developmental level may also have influenced their performance. For example, it is expected that the more difficult analogies on the inclusiveness dimension (i.e. the noninclusive types) will be incomprehensible to children until they reach a certain point of cognitive maturation. It is also possible that children's ability to comprehend problems on the functional/structural dimension will progress to the higher levels of this dimension with their advancing maturity. Investigations of these issues will shed light on the theoretical basis of my analogy dimensions, as will be discussed below.

Limitations of the Experimental Conditions Tested

The context under which the empirical results have been gathered is relatively narrow. This section will first discuss some experimental questions regarding the robustness of these findings in more ecologically valid conditions. Secondly, many of the claims made in support of my hypotheses could be more strongly made if particular experimental conditions were examined. The limitations about the experiments used in support of three such claims will be presented here: claims about priming, inclusiveness and specificity.

Broadening the experimental context. The experiments reported above used four word analogy problems presented without distractions, under conditions where subjects responded immediately. Questions that could be addressed to test the generality of these results include the following. Do the same processing distinctions exist among analogy types when they are embedded in sentences? Is the transfer of information between vehicle and target domains obstructed when time delays are introduced between presentations of the first domain (first word pair) and the second? How are solution latencies affected when distracter words are used which are strongly associated with the problem, but irrelevant to the solution?

Further priming manipulations. The reason why the blocked presentation of analogies in the priming experiment (Experiment 2) failed to significantly reduce their solution times is not completely resolved in this thesis. The central research question here is whether the demands of the task used in Experiment 2 prevented subjects from applying the cognitive effort necessary to acquire information about the association type, or whether this information is not salient in any case. That is, future research must address the possibility that even explicit knowledge of an analogy's association type might be insufficient to expedite its processing in the inference component. The discussion section of Chapter Six outlines proposals to address this question.

Further demonstrations of the inclusiveness distinction. Although inclusiveness has been described as a dimension of analogy types in this thesis, only two points on this dimension have been identified: for inclusive and noninclusive types. The dimensional nature of this distinction would be better established if associations could be found which require multiple inferences, and which produce correspondingly longer processing latencies than those already demonstrated for noninclusive types.

Further demonstrations of specificity. The processing model proposed in this thesis identifies specificity as a characteristic of analogy types that determines whether subjects will engage a procedural type of processing to solve a problem. Shorter solution latencies found for specific problems are consistent with this claim. However, this claim could be further strengthened by predicting and demonstrating the types of errors that should be evoked, according to this procedural explanation. According to this explanation of specificity, if the first word pair contains very salient information irrelevant to the analogy solution, the automatic application of this information should still occur, resulting in a negative set which wastes processing time and therefore lengthens solution latencies.

Limitations to the Empirical Support of Theoretical Claims

Two types of theoretical claims made in this thesis invite further empirical research. The first concerns the explanation of latency differences for different analogy types. The second is the assertion that the role of word attributes can be distinguished from the role of association types.

Explaining latency differences among analogy types. The focus of this thesis

thesis has been on demonstrating that problems of different analogy types show different solution latencies. More limited attention has been given to the fundamental question of how different analogy types result in the processing differences that lead to these latency differences. Two aspects of this question have been addressed in these theoretical discussions. The first concerns where in the processing model these differences occur. The second issue concerns how the nature of this processing changes between analogy types. Both of these theoretical accounts of the latency differences could be better elaborated, and would be better supported, if they were demonstrated empirically. Suggestions for empirically investigating these questions are outlined below.

Distinguishing between word attributes and association types. In the realm switching experiment the distinction between these two influences was called into question. The longer latencies for realm switched metamorphosis and object-action problems may have resulted because the word pairs within these problems were less similarly matched than in the original problems. But, this mismatch may have resulted in turn from the existence of subtypes of problems within each of these analogy types. Understanding of these two influences is limited by the lack of a clear method for empirically distinguishing between the effects of associations types and the attributes of the words making up the associations.

Future Research

Using Other Stimulus Manipulations

Several stimulus manipulations could advance our understanding about the cognitive processing of different analogy types. Increasing the level of the vocabulary in future analogy problems would determine whether the same pattern of latencies would result when this additional cognitive demand is made. The use of more analogy problems within each type would determine whether there is any empirical basis to suggest subtypes among them. Other stimulus manipulations could be performed to determine if the unlabelled corners of the corners of cube in Figure 1 could be illustrated. For example, the super/subordinate analogy **fish : minnow** as **mammal : mouse** uses similar size attributes between objects depicted in the second and fourth words. Will it therefore be processed more quickly than other super/subordinate problems, as would be expected if it constitutes a specific super/subordinate problem?

Using Different Subject Groups

Use of subject groups varying in educational and developmental levels would provide further tests of some theoretical hypotheses addressed in previous experiments. For example, the explanations of distinctions among analogy types on the functional/structural dimension and on the inclusiveness dimension both predict that younger subjects should have progressively more difficulty understanding more difficult types (i.e. top tier and noninclusive types, respectively) but not the less difficult types. That is, younger subjects should show proportionately more errors and longer latencies for these analogy types because they are hypothesized to require a more mature degree of cognitive development in subjects. This proposal could be tested by collecting solution latencies from young subjects using problem solving paradigms, or by eliciting anecdotal descriptions from these children as they attempt to solve analogy problems that tax their cognitive resources.

Another developmental study using older adults might support a different explanation of the relative difficulty of analogies on the functional/structural dimension. It is possible that latency differences between these types may become less apparent through adulthood, as older adult subjects gain experience using the association types from the higher tiers. This result would support the importance of practice on the relative difficulty of different analogy types.

Testing Additional Experimental Conditions

Further demonstrations of the inclusiveness distinction. The inclusiveness dimension could be extended by discovering associations which require multiple inferential steps for their formation (hereafter called *noninclusive+* associations), and by demonstrating that these associations lead to progressively longer solution latencies as the number of these inferential steps increases. For example, problem D in Table 18 is designed as a noninclusive+ analogy, as it requires more than one inferential step to associate the words in each pair. That is, to associate **Ruth** with **delicate glass**, the subject must infer that Ruth operates the laser, and that the laser has a threatening relationship with the delicate glass. Likewise in the second word pair, the doctor operates the X-ray machine, which in turn threatens the healthy tissue. It is expected that problem C will produce longer solution latencies than noninclusive problem B. Further, this problem should produce longer latencies than problems D or E, which are each constructed from subcomponents of the association sequence required to solve problem C. If these results are found, the dimensional nature of inclusiveness will be confirmed, and extended to this noninclusive+ level.

Further demonstrations of specificity. In illustrating how negative set might be demonstrated in four word analogy problems, consider the following problems.

1. hand : palm as **foot : sole**
2. hand : palm as **foot : toe**

In the initial stages of processing, these problems should both direct subjects' thinking the same way; the initial word pair should direct subjects to consider a whole-part relationship in which the part is a flat, open surface located in the middle of the whole object. That is, these analogies should initially produce the same mental set, which acts as a negative set when this word pair is presented with the second word pair appearing in example 2. According to my procedural explanation of specificity, when example 2 is presented in the recognition paradigm it should produce long latencies indicative of this negative set since the first word pair should automatically lead subjects to produce the specific solution word **sole**. When this strategy fails because **sole** does not appear as an answer alternative, solution latencies should be lengthened as the problem is processed first as a specific analogy, and then as a nonspecific one.

Providing Further Empirical Support of Theoretical Explanations

Locating the Source of Latency Differences Among Analogy Types

Two methods of locating the source of the latency differences between analogy types are possible; one using word association studies, the other employing a further manipulation of my problem solving paradigms. Since this issue is essentially the question of whether processing delays result from the extra time needed to recognize the association type or extra time needed to use it, this issue could be addressed through directed word association studies regarding the use and recognition of association types. The recognition study would simply determine the time required by subjects to classify association types appearing in various word pairs; the use study would measure the time subjects require to generate associates of different association types. Solution latencies produced for different analogy types in the problem solving paradigm could be compared to the data from each of the association studies to determine whether they correlate with association recognition times or association use times. This method could only be used to study the six analogy types on the front face of the cube in Figure 1, since specificity could not be manipulated in the association studies.

A second method of locating the source of processing delays in the componential model is to collect latency scores from subjects at two points during the problem solving process. Sternberg (1977) described a method for presenting his stimuli in two parts, and measuring the time subjects took to process each part. His subjects were initially shown the first word pair of the analogy and were told to press a button when they felt prepared to see the third word and solve the problem. When the first button was pushed, the rest of the problem appeared, but the initial word pair was removed from view. Subjects were then required to press a second button to indicate their solution response. With this method, two latencies are collected: one measuring the time required to encode and recognize the association in the first word pair, and a second latency measuring the time required to apply this information to the third word and produce a solution. This two-part presentation method could determine which analogy types differ in their time demands early or later in the processing system.

Identifying Qualitative Processing Differences Between Analogy Types

My processing model proposes that some analogy types (eg. specific types) require less explicit processing than others. This proposal could be investigated using tests of implicit and explicit memory to determine how information from different problem types is processed. If the third words from problems of one analogy type are best remembered in implicit tests like those used by Graf and Schacter (1985), and the third words of another type are best remembered in explicit tests, the processing of these types will be inferred to be more or less explicit, accordingly.

Distinguishing Word Attributes from Association Types

A method for empirically distinguishing between the effects of associations and the attributes of the words making up these associations must determine which distinctions among association types remain consistent across contexts. This could be accomplished by determining which subgroups of problems yield consistently different solution latencies, or by determining whether subjects are able to consistently sort problems of these subtypes.

Contributions Of The Thesis

This thesis makes empirical, methodological and theoretical contributions to analogy problem solving research. It has contributed to the methodological base of this research by introducing two new experimental paradigms which have proved useful in distinguishing the cognitive processing used in making different analogical comparisons. It has identified some important distinctions among different analogy types, and has empirically demonstrated that these distinctions have consequences for how different these analogical comparisons are in the context of solving problems. It has also contributed to the theoretical base of this field by proposing a model for understanding the processes underlying these distinctions, and by demonstrating empirical support for many aspects of this model. Furthermore, this thesis provides the background research needed to investigate a range of issues regarding analogical thinking, and has set out the framework for some of these future research projects.

Empirically, three dimensions of analogy types have been confirmed using problems constructed with words from a wide range of subject matter. The inclusiveness dimension illustrates that the time required to solve an analogy problem is determined in part by the number of inferences that must be made to form the associations within it. The specificity dimension has demonstrated that similarity between the vehicle and target domains is also a factor determining the difficulty of forming analogical comparisons. Finally, the third, functional/structural dimension indicates another factor that causes some analogy types to be more readily used than others. No exact explanation of this third dimension has been offered. However, the nature of the association types contained in analogies distinguished on this dimension suggests that different degrees of cognitive sophistication may be required to use them. Furthermore, the nature of the distinctions among these analogy types invites investigations of the role of practice and cognitive maturity to explain their relative difficulty.

The paradigms created for this thesis have proved extremely workable in many important ways. The use of four word analogy problems allows the cognitive processes involved to be tested without the influence of a highly biasing semantic context. These stimuli are easily developed, and because both stimuli and instructions are simple to understand, very little training time is required. Both recall and recognition paradigms have demonstrated reliable latency differences among analogy types, and the magnitude of these latency differences allows the effect of further stimulus manipulations to be observed. Furthermore, the general consistency of latencies produced by subjects on these two paradigms confirms the effects they have each discovered.

For a theoretical base, this thesis uses Sternberg's (1977) processing model, modified to account for the behaviour of subjects facing more than two answer alternatives. Several aspects of this model represent theoretical innovations relevant to the study of analogical thinking, generally. The components of this model provide testable predictions about how the cognitive processes distinguishing inclusive analogies from noninclusive ones, for example, affect the latencies of solutions to these problems. The model accounts for the effect of specificity by postulating a procedural short-cut through its latter components, thereby identifying a role for implicit and explicit processing in analogical thinking. The flexibility of this model accounts for the latency differences between recognition and recall paradigms by describing alternative processes involved in each. Finally, the important components of this model (inference, mapping, application and justification) are in many ways similar to those described by Gentner (1983), Holyoak (1983), and others in accounting for analogical thinking in other problem solving paradigms. One of the greatest potential contributions of this model and the empirical work supporting it then, is that the analogy types and cognitive processes demonstrated in this work might be applied to other analogy research and might enhance the understanding of analogical thinking and problem solving generally.

NOTES

1. Sternberg tests four models in this work. The model I refer to as "Sternberg's model" is the one he supports empirically, and refers to as Model III.

2. These values are arbirtrary. They were chosen post hoc as a means for identifying a few exceptional problems in each experiment using a statistical rule that could be applied evenly across experiments.

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- Objective
  - co-existence
    - co-ordination *(same level; part-part)*
    - whole-part *(different level; whole-part)*
    - part-whole *(different level; part-whole)*
  - succession
    - forward
    - backward
- Logical
  - specialisation
    - correlation *(same level; same class)*
    - specialisation *(different level; super/subordinate)*
    - generalisation *(different level; sub/superordinate)*
  - causation
    - final
    - efficient

notes. Cattell and Bryant's classification system is presented in normal type. My terminology is added in italics.

Appendix A. Cattell and Bryant's classification system for association types.

Jung (1904)	Wells (1911)
failure of response	
direct egocentric	
egocentric predicate	
judgement of quality	predicate
simple predicate	
subject relation	
object relation	
supraordinate	supraordinate
contrast	contrast
causality	
coordination	
subordination	miscellaneous
coexistence	
identity	
language-motor	
word compounding and completing	speech-habit
pure sound associations	
syntactic change	

Appendix B. Jung's and Wells' classification systems for association types.

Anderson's propositional fan explains how the memory of a proposition is influenced by recency and frequency of the concepts and associations making up that proposition. Applied to the context of four word analogies this construct predicts that the replication of a specific association in the second word pair of an analogy problem will elicit an associate relatively quickly. This is because few associates are likely to have been formed with such a specific association either recently or frequently, and so existing associates should be retrieved from memory easily. I wish to propose that the workings of propositional fans in this context can also be described using Anderson's IF-THEN production rules. I propose that this can be considered a process whereby different characteristics of an association are activated in a procedural sequence, and are then re-activated when the third word of the analogy problem has indicated that a great degree of similarity exists between the two word pairs.

Consider then, the formation of an association procedure comprised of several embedded characteristics, just as the cognitive procedure used to remember a story consists of several embedded IF-THEN productions. In the analogy **hand : palm** as **foot : sole**, for example, the first characteristic included in the cognitive procedure forming the association between the first word pair is the defining whole-part characteristic. After this defining characteristic is included, the cognitive procedure is completed by activating the other characteristics that detail its nature. In the above example these include the fact that **palm** is the contact surface of the **hand**, that it is characteristicly hairless, and that it is located in the center of the hand.

The process of deriving a solution word in four word analogy problems begins when the mapping component attempts to discover and activate attributes in the third word which match the attributes of the first word contained in the procedure making up the first association. So, the facts that **foot** is a body part which is itself made up of parts, and that **foot** has a contact surface, are both activated during mapping. Since these important attributes match those of hand, prerequisite IF conditions for the continuation of the procedure representing the first association

Appendix C: An explanation of how Anderson's propositional fan operates in four word analogies as a sequence of IF-THEN production rules linking the characteristics of an association.

are met, and the application component continues to replicate this procedure by activating the remaining characteristics of this association and applying them to the third word **foot** until the solution word has been found. For example, in the analogy **hand : palm** as **foot : sole** the solution word will first be identified as a part of the whole **foot** according to its dominant whole-part characteristic. Then the attributes of contact surface, hairlessness, center position, etc., will be applied in turn. This procedure will continue to apply the next characteristic as long as the previous one has been successfully applied. Since this example is a specific analogy, these attributes will apply successfully to the third word **foot**, and a solution word matching this set of characteristics will be found (i.e. **sole**).

How does this association procedure explain the processing advantage found for specific analogy problems relative to nonspecific ones? If this procedural type of processing is the first tried, most automatic attempt that subjects use to solve analogy problems, in the case of specific analogies it will lead to the successful discovery of a single specific solution word quickly, with little reflection or conscious effort. For nonspecific analogies however, the attempt and failure of this specific association procedure will be manifest in only partial mapping and application success. The result should be that many candidate solution words will be generated by the correspondence of only some of the word attributes and association characteristics making up the cognitive procedure formed by the first word pair.

Appendix C: An explanation of how Anderson's propositional fan operates in four word analogies as a sequence of IF-THEN production rules linking the characteristics of an association.

1	cry	weep	yell	whisper	light	coffee	shout	
2	sufficient	enough	scarce	few	scratch	adequate	bow	
3	tale	story	version	station	account	ball	myth	SYNONYMS
4	declare	claim	ask	tear	date	inquire	blind	
5	start	begin	end	stand	finish	commence	time	
6	act	actress	sing	pretend	vocalist	sink	partner	
7	hammer	pound	saw	head	mallet	pan	cut	Object-
8	rabbit	hop	whale	plant	swim	noise	hare	
9	lamp	shine	alarm	light	dense	cannon	ring	Action
10	roar	lion	squeal	pig	sun	thunder	ball	
11	bee	stinger	bird	run	wasp	bank	beak	
12	chimney	house	cone	break	volcano	like	furnace	Specific
13	foot	sole	hand	palm	step	branch	aspirin	Whole - Part
14	player	team	soldier	partner	brain	tear	army	
15	book	preface	hotel	mail	text	grant	lobby	
16	food	growth	work	meal	wealth	outlaw	warm	
17	laziness	failure	strategy	sneeze	loser	brand	victory	Cause -
18	fall	injury	disobey	punishment	tumble	beach	stream	
19	practice	skill	carelessness	repeat	smoke	errors	novel	Effect
20	cold	freeze	water	smiles	rot	chill	fuse	
21	hand	elbow	foot	pair	apple	knee	palm	
22	arm	leg	flipper	limb	test	head	tail	Relationship
23	daughter	son	mother	father	sibling	relative	man	of
24	stick	puck	racquet	ball	wine	wind	wood	
25	cloth	table	spread	leg	rash	bed	night	Parts
26	button	seam	headlight	can	light	shirt	bumper	
27	wing	beak	paw	pawn	tail	play	bird	Part-to-Part
28	eye	ear	shirt	born	lose	pants	face	
29	ball	bat	spoon	fork	base	balloon	park	
30	window	door	branch	wall	left	bunch	roots	
31	heal	doctor	lend	plum	stock	banker	menu	
32	eat	sandwich	wear	shoes	will	thistle	chew	Object -
33	ax	chop	gallows	hang	stand	hatchet	praise	
34	coat	wear	bath	went	wash	jacket	mine	Purpose
35	airplane	fly	car	write	craft	drive	transport	
36	man	bread	horse	rose	hay	bring	woman	Specific
37	barrel	wine	bushel	bold	wheat	crate	mild	Relations
38	mask	face	helmet	visor	wages	prune	head	(simple)
39	run	track	swim	stock	treaty	pool	jog	
40	water	ocean	sand	plant	rain	desert	plan	

Appendix D: Stimuli used in the recognition paradigm of the Pilot Experiments.

41	fever	sickness	cloud	replace	profile	storm	sweat	
42	scientist	facts	detective	clues	expert	fold	worst	Object-
43	mold	bread	rust	thread	fungus	iron	bark	
44	song	verse	book	harbour	chapter	blind	hymn	Characteristic
45	heavy	lead	bouyant	weight	gill	cork	track	
46	butter	margarine	juice	fat	bill	milk	needle	
47	ginger	salt	bacon	steel	spice	wiener	port	Same
48	daisy	tulip	pine	maple	archer	text	rose	
49	wrench	screwdriver	guitar	stone	piano	pliers	part	Class
50	plastic	wood	silk	last	dear	glass	nylon	
51	joy	laughter	sorrow	tears	happy	gum	capital	
52	pennant	team	flag	poison	club	crest	country	Signs/
53	beaver	work	hawk	war	squash	nest	rodent	
54	love	kiss	fatigue	lane	like	yawn	lie	Symbols
55	scales	justice	olive branch	balance	cycle	pen	peace	
56	menu	meal	map	bird	deck	trip	card	Specific
57	brandy	flask	money	wallet	wine	crude	star	
58	bandage	wound	string	patch	valve	stick	package	Relations
59	bees	hive	bats	cave	oil	wasp	row	(difficult)
60	stake	ground	nail	wind	coccoon	peg	wood	
61	birth	death	introduce	begin	plane	conclude	belief	
62	brief	long	dark	play	quick	light	air	
63	costly	cheap	few	dear	toast	many	able	Antonyms
64	idiot	genious	guest	visitor	cry	iron	fool	
65	quiet	loud	angry	contract	soft	knit	calm	
66	century	decade	minute	still	years	gold	second	
67	february	april	october	may	december	june	march	
68	dime	penny	decade	quarter	saw	year	master	Sequence
69	winter	spring	night	morning	snow	leaves	stroke	
70	then	now	past	future	before	present	show	
71	bicycle	brakes	ship	scooter	mast	limp	earl	
72	school	gym	restaurant	hand	fold	lounge	class	Whole-Part
73	tree	leaf	turtle	pen	test	bush	shell	
74	orchestra	violins	army	bottles	bands	rifles	burns	
75	chair	leg	door	bench	serve	hinge	coach	
76	animal	dog	insect	beetle	organism	king	show	Super-/Sub-
77	tool	chisel	machine	aid	telephone	throw	skip	
78	entertainment	ballet	ceremony	contract	cane	wedding	perform	Ordinant
79	furniture	chair	appliance	field	stove	effects	cell	
80	beverage	wine	food	cake	club	hope	drink	

Appendix D: Stimuli used in the recognition paradigm of the Pilot Experiments (continued).

Study of Meaning Structures Through Analogy and Word Associations
Experimenters: David Moroson (228-6487) and Dr. Peter Graf (228-6635)
Location: Rm 1222 Kenny Building (Dept of Psychology)

This study examines how university students respond to different types of word associations. You will be presented with analogy problems and we will observe what responses you make toward them. Consider the following analogy:

fish : school
goose : ____

How did you go about solving this problem? Probably by realizing that a group of fish is called a school and then applying the same relationship to 'goose'. Since a group of geese is called a goggle, this is the correct word solution to this analogy. In the experiment, 75 analogies are presented. In one condition, the analogy problem is presented as a multiple choice test, as follows:

fish : school
goose : ____
a) pack b) minnow c) goggle d) egg

The subject must then pick the correct solution from the alternatives. In the second condition no response alternatives are presented and the subject must generate their own solution. Thus, the independent variable is the type of presentation the subject is exposed to. There is also a condition in which some subjects are shown a series of single words and asked to say out loud other words that come to mind when thinking of these words. This is being done to see if the kinds of associations we are presenting in the analogies are the same types that people naturally have to the words we are using.

When we get the information from our adult subjects we hope to use similar problems to collect responses from younger subjects (ages 5-7) and older subjects (+65 years). The purpose is to determine what happens to the meaning of words and their relationship to each other through the course of their life. We expect there to be a pattern of difficulty among the different analogies which would allow children to solve some but not all of them. We are interested in determining if this pattern also exists among elderly subjects who are suffering from mental deterioration due to aging.

If you are willing to participate in the present research, you will be offered course credit and will be required for about 45 minutes. You may stop participating at any time in the course of the experiment and no penalty will result from your doing so. The fact that you stopped participating will not be reported to anyone.

If you would like to participate in this study, please sign the bottom of this form. The results of your participation in this study will be kept strictly confidental. Listed below are two articles that you can read if you are interested in the issues examined by this study. The first has to do with analogy problems and the second relates to word association work. If you have any questions about this research at any time in the future, please feel free to call or contact one of the experimenters listed above.

Holyoak, K.J. & Koh, K. (1987). Surface and structural similarity in analogical transfer. Memory and Cognition, 15, 332-340.

Gentner, D. (1983). Structure-mapping: the theoretical framework for analogy. Cognitive Science, 7, 155-170.

Meaning Associations Study

I agree to participate in the study and I realize I am free to discontinue at any time. I have been given the summary of the study, I have read it, and I understand the nature and procedure of the experiment.

Appendix E: Consent form and introductory instructions used for all studies.

Whole-Part

book : spine
elevator : door
brush : bristles
school : gym
desert : tumbleweed
teapot : spout
orchestra : violins
chair : leg
highway : median
tree : leaf
pencil : lead*
escalator : stairs*
cigarette : filter*
restaurant : kitchen*
beach : sand*
clock : hands**
choir : soprano**
door : handle**
river : bank**
flower : petal**

Specific Whole-Part

pool cue : chalk
book : chapter
chair : legs
library : book
foot : sole
team : player
snake : skin
apple : core
organ : keys
volcano : lava
skis : wax
play : act
car : wheels
pharmacy : drug
hand : palm
army : soldier
rabbit : fur
peach : pit
guitar : strings
chimney : smoke

Part-Part

floor : door
bumper : headlight
knife : fork
wax : wick
neck : leg
beak : wing
rail : ties
toilet : tub
ear : eye
balance beam : trampoline
chimney : roof*
sail : mast*
saucer : plate*
lampshade : bulb*
roots : branches*
paw : tail**
spokes : hub**
stove : fridge**
stomach : kidney**
swingset : slide**

Appendix F: Stimulus set used in the main experiments.

Specific Part-Part

gravy : meat
tobacco : pipe
lungs : skin
blossom : stem
helmet : visor
puck : rink
stern : bow
acorn : leaf
arm : leg
hand : elbow
dressing : salad
coffee : cup
gills : scales
flag : pole
eye : lid
ball : field
caboose : engine
pinecone : needle
flipper : fin
foot : knee

Same Class

doctor : engineer
ant : mosquito
Latin : French
apple : cherry
pants : shirt
wrench : screwdriver
pork : beef
tennis : golf
chair : bed
daisy : tulip
plumber : electrician*
lizard : snake*
New Zealand : Peru*
potato : carrot*
necklace : ear-ring*
flute : clarinet**
shrimp : scallops**
gin rummy : poker**
dishwasher : stove**
pine : oak**

Super/Subordinate

hobby : model-building
animal : bear
professional : lawyer
meat : bacon
flower : rose
reptile : turtle
clothing : sweater
fruit : banana
furniture : table
sport : soccer
pet : dog*
bird : crow*
tradesman : welder*
seafood : lobster*
tree : maple*
insect : ant**
jewelery : ring**
vegetable : corn**
appliance : stove**
game : monopoly**

Appendix F: Stimulus set used in the main experiments (continued).

Object-Action

lovers : kiss	mourners : cry*
plaster : crack	stocking : run*
nose : smell	eyes : see*
airplane : fly	ship : sail*
lion : roar	pig : squeal*
hammer : pound	knife : cut**
elastic : stretch	glue : stick**
potato : bake	bacon : fry**
lamp : shine	alarm : ring**
rabbit : hop	whale : swim**

Metamorphosis

plum : prune	grape : raisin*
catterpillar : butterfly	tadpole : frog*
apprentice : carpenter	intern : doctor*
seedling : tree	bud : flower*
sand : cement	pulp : paper*
cow : hamburger	pig : bacon**
barley : beer	grapes : wine**
clay : pottery	dough : bread**
water : ice	rain : snow**
acorn : oak	bulb : tulip**

note. Asterisks indicate problems grouped together for the purpose of constructing realm switched problems for Experiment 5.

Appendix F: Stimulus set used in the main experiments (continued).

Mean Solution Latencies From Subjects Analysis, Judges Analysis, and Items Analysis in Experiment 1B

Analysis	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
Subjects:	3630	5279	5695	4646
Judges:	3628	5248	5605	4704
Items:	3434	4917	5267	4643
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
Subjects:	2919	4225	4736	3179
Judges:	2928	4185	4736	3179
Items:	2825	3599	4327	2944

note. latencies are given in milliseconds.

Source tables for 2 X 2 ANOVA on mean solution latencies testing analogy types from top tier of typology cube in Figure 1.

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	5976954.0	23		
Specificity(A)	40117632.0	1	33.6	.001
AXS-W	1195430.0	23		
Inclusiveness(B)	35859456.0	1	35.7	.001
BXS-W	1003809.4	23		
AXB	1676544.0	1	2.0	.166
AXBXS-W	820535.6	23		

Appendix G. Comparison of subjects analysis, judges analysis and items analysis for recognition data of Experiment 1.

Judges Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	5682476.0	23		
Specificity(A)	36271488.0	1	30.0	.001
AXS-W	1209444.0	23		
Inclusiveness(B)	34367232.0	1	35.7	.001
BXS-W	962671.3	23		
AXB	257894.0	1	2.9	.102
AXBXS-W	888553.7	23		

Items Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Specificity(A)	10064162.0	1	13.6	.001
Inclusiveness(B)	17400160.0	1	23.5	.001
AXB	1439520.0	1	1.9	.171
Subjects-within	739264.0	36		

Appendix G: Comparison of subjects analysis, judges analysis, and items analysis for recognition data of Experiment 1 (continued).

Evaluation of Priming Experiment Results as a Replication of Experiment 1

Since the effects of this priming manipulation were not large in magnitude, the pattern of solution latencies across analogy types was similar in this experiment to that of Experiment 1. To directly test whether similar effects exist, the same series of statistical analyses were used as those used for the data of Experiment 1. This consisted of separate analyses on the data from recognition and recall paradigms, followed by analyses comparing the data from the two paradigms.

Testing Differences Among Analogy Types Separately for Each Paradigm

The mean latency scores for each analogy type are plotted in Appendix K for both recognition and recall paradigms. A pair of 2 X 2 ANOVA were performed on the four critical analogy types at the top tier of the cube in Figure 1 to test specificity and inclusiveness effects, separately for each paradigm. In the recognition data, the analysis confirmed both main effects of inclusiveness, $F(1,23) = 20.8$, $MS_e = 498976.8$, and specificity $F(1,23) = 21.3$, $MS_e = 402398.6$. A significant interaction between these factors was also evident ($F(1,23) = 7.7$, $MS_e = 200169.7$, $p < .02$), indicating that the specificity effect was not as large for part-part types as it was for whole-part types. In the recall data, both main effects of inclusiveness, $F(1,23) = 33.0$, $MS_e = 1465210.0$ and specificity $F(1,23) = 58.1$, $MS_e = 819979.2$, were confirmed as hypothesized, and no interaction was present ($F < 2.5$).

The mean latencies from this Priming Experiment also show that the inclusiveness effect appears in each of the three pairs of analogy types along the functional/structural dimension, and that latencies differ across the three levels of this dimension. As in Experiment 1, a pair of 2 X 3 repeated measures ANOVA were performed on the six analogy types forming the front face of the cube in Figure 1 to test these effects. In the recognition data clear effects of both inclusiveness, $F(1,23) = 9.6$, $MS_e = 768178.1$, $p < .005$, and the structural/functional dimension, $F(2,46) = 30.0$, $MS_e = 514765.9$, were found. The interaction between these effects was also significant, $F(2,46) = 4.4$, $MS_e = 288517.6$, $p < .02$. The recall data confirmed these same effects of inclusiveness, $F(1,23) = 28.0$, $MS_e = 1439243.0$, and the functional/structural dimension $F(2,46) = 78.3$, $MS_e = 702502.9$, and again these factors interacted, $F(2,46) = 3.6$, $MS_e = 760108.5$, $p < .04$.

Appendix H. Evaluation of Priming Experiment Results as a Replication of Experiment 1

In order to determine which particular pairs of analogy types were responsible for the interactions found in the above analyses, a series of Newman-Keuls multiple comparisons were performed on the data from each paradigm. These comparisons tested the difference of each adjacent pair of analogy types in the typology cube of Figure 1. The results of these comparisons for the data from both paradigms are presented in Appendix K.

In the recognition data, Appendix K shows that for all pairs of analogy types distinguished by the inclusiveness dimension, except the object-action and metamorphosis pairs, inclusive types are more quickly solved. These comparisons also show that the difference between part-part and specific part-part analogies is not significant. This finding contrasts with the results of Experiment 1 where this difference was significant. In all other aspects, hypotheses concerning specificity, inclusiveness, and functional/structural dimensions were again confirmed by these analyses.

Multiple comparisons performed on the recall data revealed similar effects to those found in the recognition data; the latencies of all analogy pairs distinguished by inclusiveness showed the inclusiveness type to be more quickly solved, except the metamorphosis and object-action pair. Unlike the data from the recognition paradigm however, both of the pairs of analogies distinguished by specificity confirmed a processing advantage for specific problems. Thus, the pattern of results displayed in the recall data of Experiment 1 was replicated in this study, and confirms all three hypotheses concerning the specificity, inclusiveness, and functional/structural dimensions.

Alternate analyses. As in Experiment 1 the consistency of latencies for the ten problems of each type was tested through an alternate scoring scheme referred to as the items analysis. These items analyses showed mean latency values very similar to those of the subjects analysis reported above. Details of the results of these analyses appear in Appendix I for the recognition paradigm, and Appendix J for the recall paradigm.

Also appearing in Appendix J are the results of an analysis performed on data scored by alternate judges of responses in the recall paradigm. As was the case in Experiment 1, this alternate judges' analysis showed little discrepancy from the original subjects analysis.

Appendix H. Evaluation of Priming Experiment Results as a Replication of Experiment 1 (continued).

Comparing Recognition and Recall Paradigms

In order to compare paradigms using the data from the four analogy types on the top tier of Figure 1, a 2 X 2 X 2 ANOVA was conducted to test specificity, inclusiveness and the difference between paradigms. The results of this analysis parallel those of Experiment 1. Main effects were found for both inclusiveness $F(1,46) = 52.7$, $MS_e = 981593.0$, and specificity $F(1,46) = 79.0$, $MS_e = 611183.3$, but the main effect between the two experimental paradigms was not significant ($F < 1$). However, the latencies of the two paradigms interacted with both specificity, $F(1,46) = 12.9$, $MS_e = 611183.3$, and inclusiveness, $F(1,46) = 7.1$, $MS_e = 981593.0$, $p < .01$. Both of these interactions were similar to those of Experiment 1; the specificity effect was enhanced in the recall data relative to the recognition data, and the difference in solution latencies between noninclusive part-part analogies and inclusive whole-part analogies was greater in the recall paradigm than in the recognition paradigm.

A mixed design, 2 X 3 X 2 ANOVA tested the effect of the two paradigms across the three pairs of analogy types on the front face of the cube in Figure 1. As in Experiment 1, main effects were found for both inclusiveness $F(1,46) = 37.1$, $MS_e = 1103872.0$, and the structural/functional dimension $F(2,92) = 103.7$, $MS_e = 608656.7$, but no overall difference between the latencies of the two paradigms was found, $F < 1$. Also consistent with Experiment 1, latencies from the two paradigms did interact with both inclusiveness, $F(1,46) = 6.0$, $MS_e = 1103872.0$, $p < .02$, and the structural/functional dimension, $F(2,92) = 12.0$, $MS_e = 608656.7$.

Appendix H. Evaluation of Priming Experiment Results as a Replication of Experiment 1 (continued).

Mean Solution Latencies From Subjects Analysis and Items Analysis in Experiment 2A

Analysis	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
Subjects:	3481	4131	4708	4364
Items:	3366	3824	4664	4492
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
Subjects:	3325	3333	4305	3454
Items:	3181	3358	4136	3442

note. latencies are given in milliseconds.

Source tables for 2 X 2 ANOVA on mean solution latencies testing analogy types from top tier of typology cube in Figure 1.

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	5119376.0	23		
Specificity(A)	8569344.0	1	21.3	.001
AXS-W	402398.6	23		
Inclusiveness(B)	10342272.0	1	20.8	.001
BXS-W	497986.8	23		
AXB	1539456.0	1	7.7	.011
AXBXS-W	200169.7	23		

Appendix I. Comparison of subjects analysis and items analysis for recognition data of the Priming Experiment.

Items Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Specificity(A)	1877440.0	1	4.2	.049
Inclusiveness(B)	6231521.0	1	13.8	.001
AXB	677600.2	1	1.5	.229
Subjects-within	451562.6	36		

Appendix I. Comparison of subjects analysis and items analysis for recognition data of the Priming Experiment (continued).

Mean Solution Latencies From Subjects Analysis, Judges Analysis, and Items Analysis in Experiment 2B

Analysis	Analogy Type			
	Metamorphosis	Same Class	Part-Part	Spec. Part-Part
Subjects:	3266	4918	5654	4592
Judges:	3272	4926	5662	4575
Items:	3215	4612	5362	4695
	Object-action	Super/subord.	Whole-part	Spec. Whole-part
Subjects:	2693	3392	4580	2825
Judges:	2666	3396	5668	4575
Items:	2703	3197	4331	2689

note. latencies are given in milliseconds.

Source tables for 2 X 2 ANOVA on mean solution latencies testing analogy types from top tier of typology cube in Figure 1.

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	4167245.0	23		
Specificity(A)	47638272.0	1	58.1	.001
AXS-W	819979.1	23		
Inclusiveness(B)	48410880.0	1	33.0	.001
BXS-W	1465210.0	23		
AXB	2883456.0	1	2.5	.130
AXBXS-W	1167037.0	23		

Appendix J. Comparison of subjects analysis, judges analysis, and items analysis for recall data of Experiment 2.

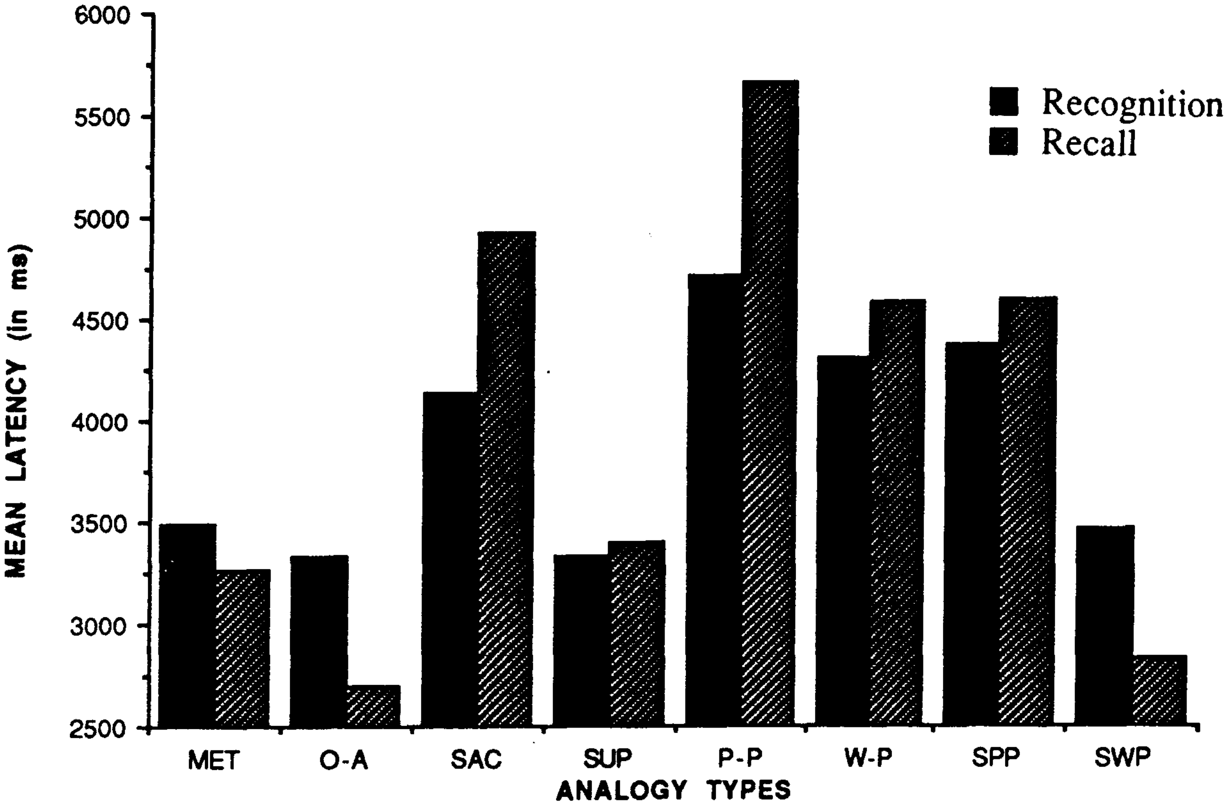
Judges Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	420949.0	23		
Specificity(A)	47975424.0	1	58.2	.001
AXS-W	823997.2	23		
Inclusiveness(B)	47608704.0	1	33.7	.001
BXS-W	1411795.0	23		
AXB	2466816.0	1	2.1	.157
AXBXS-W	1152289.0	23		

Items Analysis

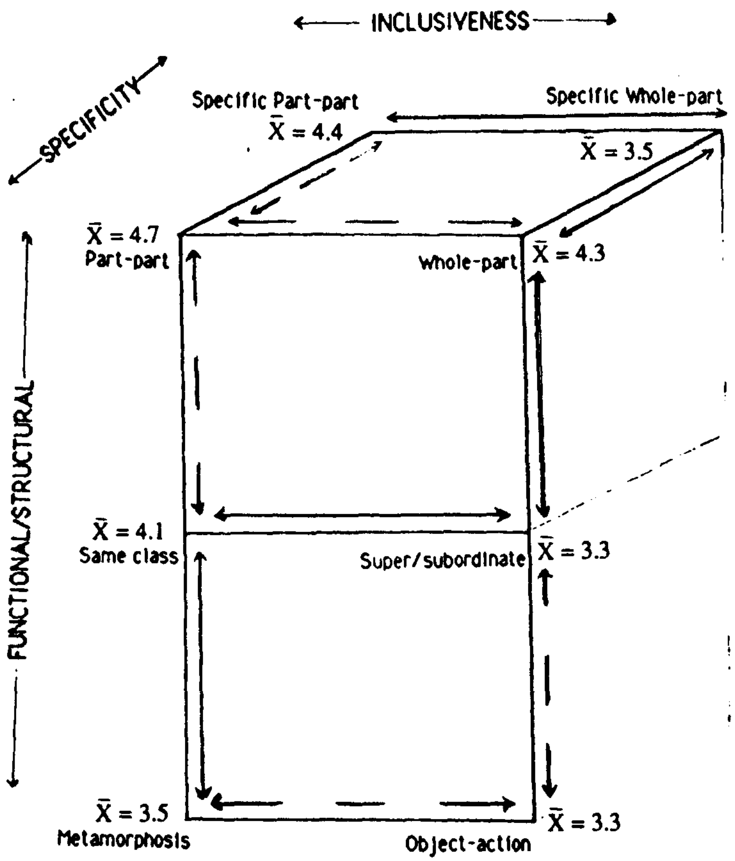
Source	Mean Squares	Degrees of freedom	F ratio	probability
Specificity(A)	13341443.0	1	12.7	.001
Inclusiveness(B)	23066080.0	1	22.0	.001
AXB	2375040.0	1	2.3	.141
Subjects-within	1047985.8	36		

Appendix J. Comparison of subjects analysis, judges analysis, and items analysis for recall data of Experiment 2 (continued).

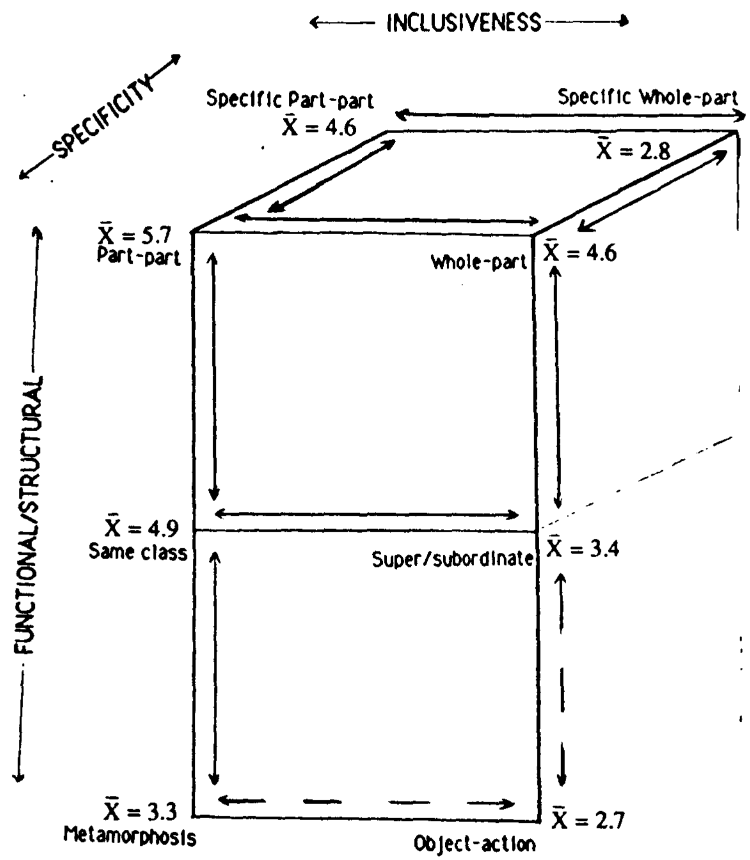


Appendix K. Figures and tables comparing recognition and recall data in Experiment 2.

Appendix K. Figures and tables comparing recognition and recall data in Experiment 2 (continued).



Experiment 2A: recognition data



Experiment 2B: recall data

<u>notes.</u> means are expressed in seconds.
⟵⟶ solid lines indicate significant differences between means; broken lines
← – → indicate nonsignificant differences (alpha = .05)

Results of Newman-Keuls multiple comparisons in Priming Experiment.

Error Rates in Experiment 2 for Each Analogy Type

Analogy Type	Errors in Exp't 2A	Errors in Exp't 2B
W-P	2	14
SW-P	1	4
P-P	5	44
SP-P	3	26
SA CLA	1	14
SUPS	1	7
OB-ACT	3	4
META	3	23
Total	19	136

Appendix K. Figures and tables comparing recognition and recall data in Experiment 2 (continued).

Outliers

Stimulus Stem	Answer Alternative	Analogy Type	Z-scores(2A,2B)
plaster : crack :: stocking	run	object-action	2.01, 2.43

Inconsistent Problems

Stimulus Stem	Answer Alternative	Relation Type	Z-scores(2A,2B)
bumper : headlight :: sail :	mast	part-part	-.49, 1.67
rail : ties :: spokes:	hub	part-part	2.10, -.34
helmet : visor :: eye :	lid	spec part-part	2.24, -.75
ant : mosquito :: lizzard :	snake	same class	-.31, 1.80
apple : cherry :: potato:	carrot	same class	-1.72, 1.42
hobby : model-building : pet :	dog	super/subordinate	1.82, -.98
sport : soccer :: game :	monopoly	super/subordinate	-.21, 2.16

note. 2A indicates recognition paradigm in Experiment 2A
2B indicates recall paradigm in Experiment 2B

Appendix L: Outlying and Inconsistent Problems in Experiment 2

Analogy Type	Recognition Errors			Free Recall Errors		
	Expt 1A	Expt 3A	Increase	Expt 1B	Expt 3B	Increase
W-P	2	8	6	21	68	47
SW-P	1	3	2	8	10	2
P-P	6	3	-3	50	42	-8
SP-P	5	7	2	36	39	3
SA CLA	4	1	-3	32	29	-3
SUPS	3	2	-1	15	18	3
OB-ACT	6	4	-2	7	28	21
META	5	2	3	32	38	6
TOTAL	26	30	4	201	272	71

note. total possible errors for each type is 240 (10 problems X 24 subjects).

Appendix M: Error rates in Experiment 1 and the Reordering Experiment, for each analogy type.

Specific Whole-part Problems	Nonspecific Whole-part Problems
1. pool cue : chalk skis : wax	racket : strings skis : bindings
2. book : chapter play : act	textbook : references play : act
3. chair : legs car : wheels	desk : drawer car : wheels
4. library : book pharmacy : drug	garage : gas pump pharmacy : drug
5. foot : sole hand : palm	face : eye hand : finger
6. team : player army : soldier	team : goaltender army : soldier
7. snake : skin rabbit : fur	sparrow : wing rabbit : fur
8. apple : core peach : pit	cabbage : leaf peach : pit
9. organ : keys guitar : strings	saxophone : mouthpiece guitar : strings
10. volcano : lava chimney : smoke	window : sill chimney : smoke

Appendix N. Specific problems from Experiment 1 and nonspecific problems generated from them in the Specificity Experiment (Exp't 4).

Specific Part-part Problems	Nonspecific Part-part Problems
1. gravy : meat dressing : salad	tea : cream dressing : salad
2. lungs : skin gills : scales	feathers : beak gills : scales
3. blossom : stem flag : pole	picture : frame flag : pole
4. helmet : visor eye : lid	waist : shoulder eye : nose
5. stern : bow caboose : engine	windshield : door caboose : engine
6. acorn : leaf pinecone : needle	thorn : bud pinecone : needle
7. arm : leg flipper : fin	head : belly flipper : fin
8. hand : elbow foot : knee	nose : ear foot : knee
9. tobacco : pipe coffee : cup	soup : crackers coffee : cup
10. puck : rink ball : field	racket : net ball : field

Appendix N. Specific problems from Experiment 1 and nonspecific problems generated from them in the Specificity Experiment (continued).

Statisical Analysis Comparing Paradigms Separately at Each Level of the Functional/structural Dimension

This section reports on further statistical analyses performed to compare the effect of realm switching across paradigms. Three 2 X 2 X 2 ANOVAs were performed on the latencies from analogy types at each of the three tiers of the cube in Figure 1. They tested the effects of realm switching (i.e. Experiments 1 vs 5), the difference between recall and recognition paradigms, and the inclusiveness distinction, separately at each level of the functional/structural dimension.

The analyses performed on the analogy types from the top and bottom tiers found no effects regarding the interaction of realm switching with paradigms. For the ANOVA testing whole-part and part-part analogy types, the main effect between experiments, and all interactions involving it yielded $\underline{F}$ values less than 1. In the ANOVA for the metamorphosis and object-action types, a main effect of realm switching was found, $\underline{F}(1,91) = 6.4$, $\underline{MS}_e = 7964624$, confirming the results of the multiple comparisons reported in Chapter Eight. For all other effects and interactions in this ANOVA, $\underline{F}$ values were less than 2. Figures portraying the means involved in these analyses appear at the end of this appendix.

The analysis of the data for the same class and super/subordinate analogies, portrayed in the figure immediately below, produced more complicated results. The ANOVA revealed a main effect between paradigms, $\underline{F}(1,91) = 5.5$, $\underline{MS}_e = 3939730$, indicating longer latencies for the recall paradigm than the recognition paradigm, and this effect is complicated by interactions. First, a significant inclusiveness effect found in this analysis, $\underline{F}(1,91) = 60.4$, $\underline{MS}_e = 604911.1$, interacts between paradigms, $\underline{F}(1,91) = 14.9$, $\underline{MS}_e = 604911.1$. This interaction occurs because the latency difference between super/subordinate and same class analogy types is greater in the recall paradigm than in the recognition paradigm. Furthermore, a three-way interaction between this interaction and the two experiments is also significant, $\underline{F}(1,91) = 5.0$, $\underline{MS}_e = 604911.1$. As the accompanying figure indicates, this interaction occurs because the two-way interaction between analogy types and paradigms is greater in the realm switching experiment than in Experiment 1. No other effects in this ANOVA were significant ($\underline{F}$ values < 1).

Appendix O: Further analysis and discussion of the data from the Realm Switching Experiment.

Discussion of the Interaction of Realm Switching Across Paradigms for Super/subordinate and Same Class Analogy Types.

An interaction was found between realm switching and the paradigms, for super/subordinate and same class types. Furthermore, this interaction takes different forms for these two analogy types. For same class analogy problems realm switching resulted in greater latency increases in the recall paradigm than in the recognition paradigm. For super/subordinate problems, this pattern was reversed; latencies increased with realm switching in the recognition paradigm only. While the following explanation of this result is speculative, it is noteworthy that a tendency toward this same three-way interaction also appears in the data from the other two tiers. (See the end of this appendix for figures depicting this.) In light of this, I believe a complex explanation like the one that follows is required to account for the cognitive processing that produced these data.

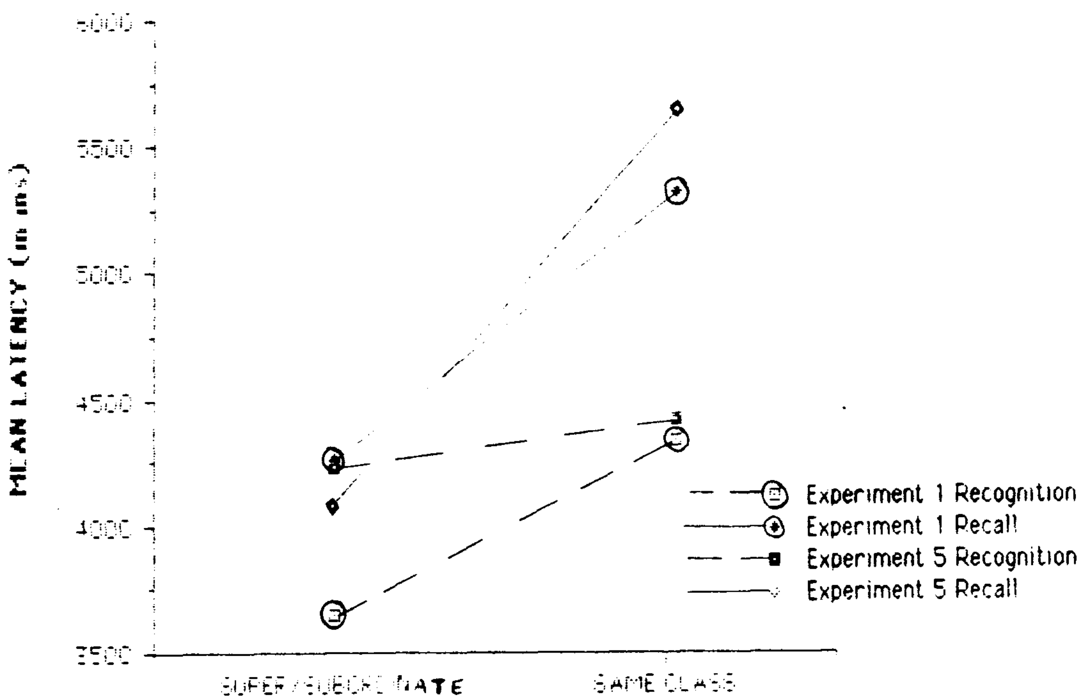
For the super/subordinate type, I propose that realm switching activates a type of cognitive processing I will characterize as procedural. This means the subject applies the representation of the association formed in the first word pair in a highly automated way, with little reflection about the details of the words involved. This processing leads to a quickly generated solution response, and a less elaborately processed category, since no reflection is required to produce the single solution response alternative, and hence no other alternatives are considered.

This type of processing is activated because as the subject matter of the second word pair becomes more remote, the subject becomes less inclined to map details about the subject matter of the first word pair, and more certain that very general information about the association type is sufficient to solve the problem. To illustrate, for originally constructed problems such as **fruit : banana** as **vegetable : ____** , where two closely related subjects are involved (**fruit** and **vegetable**), subjects may consider the possibility that other characteristics of **banana** might apply analogously to the solution word. Such characteristics might include the color of the second category member, its geographic origin, etc.

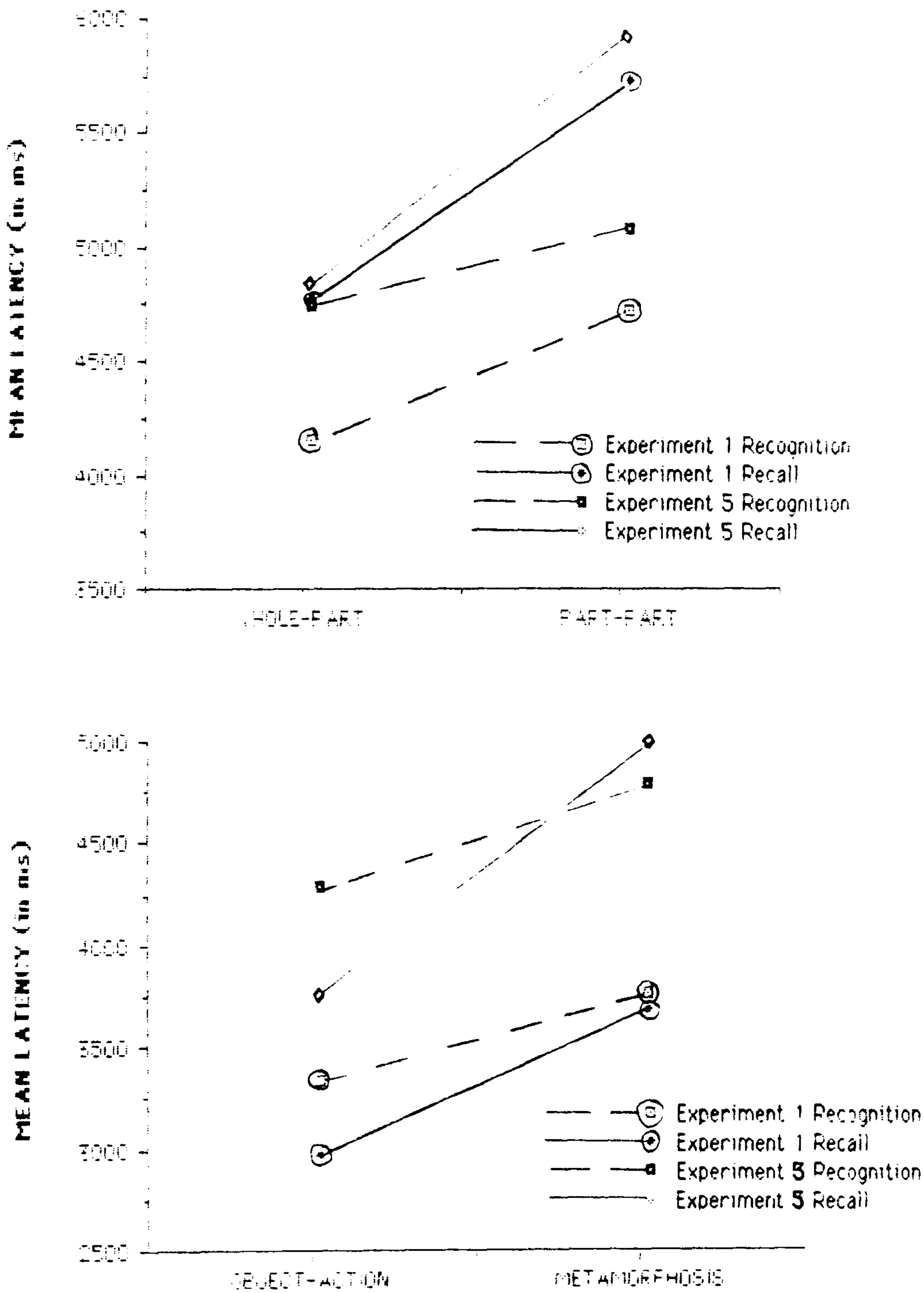
In contrast, for a realm switched problem such as **clothing : sweater** as **vegetable : ____** , where little taxonomic similarity exists between word pairs, the subject probably relies on a more superficial representation of the association, and may solve the problem using a simple language procedure such as "an example of a vegetable is a ____". This would require less elaborate processing of the category. This automatic application of such a simple super/subordinate association procedure for the **clothing : sweater** as **vegetable : ____** analogy would explain the relatively fast solution times found for realm switched super/subordinate analogies in the recall paradigm; the processing of an association at such a superficial level would be time saving. Likewise, this type of processing would also result in longer latencies for realm switched problems in the recognition paradigm; subjects who initially process the second category (eg. **vegetable**) superficially will often be forced to reconsider this category (i.e. repeat the mapping component) when their chosen solution word does not appear among the multiple choice alternatives.

For same class analogy problems, realm switching should change subjects' processing activities in opposite ways. Processing should become more reflective and deliberate, leading to the consideration of more solution alternatives. This should result from the uncertainty created by the presence of more widely divergent subjects areas within a problem, combined with the need to infer the superordinate class in each problem. For example, in the realm switched analogy **soccer : badminton** as **dog : _____** , the word **dog** can be interpreted as a member of the categories **domestic animals, working animals, mammals, dangerous animals, living things, pets,** and many others. The uncertainty as to which superordinate category is appropriate may be particularly problematic because in realm switched analogies the first word pair (eg. **soccer : badminton**) offers virtually no guidance as to the nature of this category. In contrast, in the original same class analogy **robin : sparrow** as **dog : _____** , the category depicted by **robin : sparrow** provides subjects a reference with which to judge the level and nature of the category to be used with **dog**.

In summary, the interactions found for the data of these analogy types can be explained by two main points. The first is that longer latencies for realm switched super/subordinate analogies in the recognition paradigm result from the ready use of superficial association procedures between word pairs, and the extra processing that may be required to compensate for this lack of processing depth when the multiple choice alternatives are presented. The second is that the long latencies for realm switched same class analogies in the recall paradigm reflects the extra time required to determine the category membership of words when many levels of categorization are possible for these words.



Appendix O: Further analysis and discussion of the data from the Realm Switching Experiment (continued).



Appendix O: Further analysis and discussion of the data from the Realm Switching Experiment (continued).

Analogy Type	Recognition Errors			Free Recall Errors		
	Expt 1A	Expt 5A	Increase	Expt 1B	Expt 4B	Increase
W-P	2	5	3	21(13)	50(18)	29
P-P	6	4	-2	50(32)	87(31)	37
SA CLA	4	5	1	32(20)	41(15)	9
SUPS	3	2	-1	15(10)	19(7)	4
OB-ACT	6	3	-3	7(4)	44(16)	37
META	5	5	0	32(20)	39(14)	7
TOTAL	26	24	-2	157	280	123

notes. total possible errors for each type is 240 (10 problems X 24 subjects). bracketed figures refer to percentage of total errors in that experiment committed on each analogy type.

Appendix P: Error rates in Experiment 1 and the Realm Switching Experiment, for each analogy type.

SORTING INSTRUCTIONS

YOU ARE BEING ASKED TO SORT THE ANALOGIES YOU HAVE BEFORE YOU INTO CATEGORIES. **THESE CATEGORIES SHOULD BE BASED ON THE TYPES OF RELATIONSHIPS (ASOCIATIONS) THAT EXIST BETWEEN THE WORDS IN THE ANALOGIES.** DO NOT SORT THEM ACCORDING TO THE SUBJECT MATTER OF THE WORDS IN THE ANALOGIES. LOOK AT THE ASSOCIATION BETWEEN THE FIRST AND SECOND WORD IN THE ANALOGY (AND BETWEEN THE THIRD AND FOURTH WORD). GROUP ALL ANALOGIES THAT USE A SIMILAR RELATIONSHIP INTO THE SAME CATEGORY. USE BETWEEN FOUR AND TEN CATEGORIES.

A GOOD STRATEGY TO USE IS TO FIRST TURN THE SLIPS OF PAPER OVER SO THAT THEY FACE UP AND READ ALL THE ANALOGIES. THEN FIND A FEW ANALOGIES THAT USE A SIMILAR RELATIONSHIP (ASSOCIATION) AND USE THEM TO START A CATEGORY. DO THE SAME WITH OTHER GROUPS UNTIL YOU CAN'T SEE ANY OTHER CATEGORIES AMONG THEM. NOW TRY TO FIT THE REMAINING ANALOGIES INTO THE GROUPS YOU HAVE CREATED. AS YOU DO THIS LAST STEP YOU MAY WANT TO CREATE NEW CATEGORIES, OR JOIN TWO CATEGORIES TOGETHER. WHEN YOU FINISH, ALL THE ANALOGIES SHOULD BE INCLUDED IN THE GROUPS YOU HAVE CREATED.

REPORTING THE GROUPS

NOW YOU ARE BEING ASKED TO DESCRIBE THE CATEGORIES YOU HAVE CREATED BY SPEAKING INTO THE TAPE RECORDER. DO THIS BY SAYING THE FOLLOWING THINGS:

1) SAY YOUR NAME AND THE NUMBER OF CATEGORIES YOU HAVE CREATED.

2) STARTING WITH ANY CATEGORY, READ ONE OF THE ANALOGIES THAT REPRESENTS THE CATEGORY IT BELONGS TO. THEN EXPLAIN THE NATURE OF THE RELATIONSHIP (ASSOCIATION) THAT IS USED IN THE ITEMS IN THIS CATEGORY. IN OTHER WORDS, WHAT IS THE RULE YOU USED TO PUT ITEMS IN THIS CATEGORY? YOU MAY WANT TO USE AN EXAMPLE AS YOU DESCRIBE THE CATEGORY.

3) REPEAT STEP 2) FOR EACH OF THE CATEGORIES YOU CREATED.

Appendix Q. Instructions given to subjects in the sorting task.

1	16
2	19	17
3	18	19	20
4	18	14	20	18
5	14	12	15	14	18
6	16	14	16	17	16	13
7	16	14	16	15	15	12	15
8	15	16	17	17	14	12	16	15
9	15	15	15	14	16	15	13	13	16
10	04	08	05	05	04	05	06	06	08	09
11	14	14	18	15	18	14	13	14	14	14	07
12	17	17	19	19	17	12	16	13	15	12	03	15
13	12	15	14	14	14	17	11	14	14	15	08	17	12
14	14	14	14	16	15	12	16	12	13	13	03	14	16	12
15	14	12	15	14	16	18	15	13	14	16	07	14	14	16	12
16	14	15	14	15	13	10	15	14	15	17	07	11	14	12	14	14
17	14	13	17	13	15	12	11	14	13	15	07	16	13	11	09	13	12
18	16	16	19	18	18	14	16	14	17	16	06	16	18	15	16	18	16	13
19	09	09	09	10	10	13	09	10	09	11	03	08	10	12	11	11	12	09	11
20	02	03	03	03	03	01	06	03	02	02	09	06	02	03	05	02	04	05	01	02
21	06	08	05	07	05	02	06	07	06	06	05	08	05	05	07	04	09	09	05	02	10
22	02	03	01	01	00	00	01	02	01	01	06	01	01	01	01	01	02	02	01	00	09	05
23	09	08	08	09	07	07	07	06	07	10	07	07	07	07	10	05	11	08	07	06	05	09	02
24	04	03	01	02	01	00	05	02	01	01	05	03	02	00	05	01	04	03	01	00	14	13	07	07
25	08	09	08	07	07	07	06	08	09	10	09	07	06	06	05	07	08	10	08	05	06	09	06	08	08
26	02	04	00	01	00	00	02	01	01	01	04	02	01	01	03	00	02	01	00	01	09	08	10	05	10	03
27	02	01	01	01	01	00	03	01	03	02	04	03	01	00	04	02	03	03	02	00	10	10	07	05	15	08	10
28	02	03	00	01	00	00	02	00	00	00	03	01	01	00	04	00	01	00	00	00	10	06	13	04	11	04	17	10
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30	02	04	02	02	01	00	00	03	02	02	13	04	01	05	02	03	04	04	02	01	09	08	08	06	06	06	07	06	07	05
31	03	06	03	03	02	03	01	06	03	04	10	04	02	06	02	05	03	05	03	03	06	06	05	05	04	08	05	04	04	04	15
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36	03	03	03	03	02	01	03	03	04	04	06	03	02	02	03	04	06	03	04	01	08	10	12	07	13	08	09	15	08	06	05	04	10	07	04	08
37	06	06	06	06	07	07	06	07	08	06	05	07	05	07	05	08	06	07	06	05	03	07	06	07	04	05	03	05	03	05	04	03	05	06	08	03	06
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45	00	02	00	01	00	00	03	00	01	01	03	01	00	00	03	01	02	00	01	00	07	05	13	01	06	04	13	07	14	15	02	01	07	03	01	03	08	03	08	07	18	16	19	18	19
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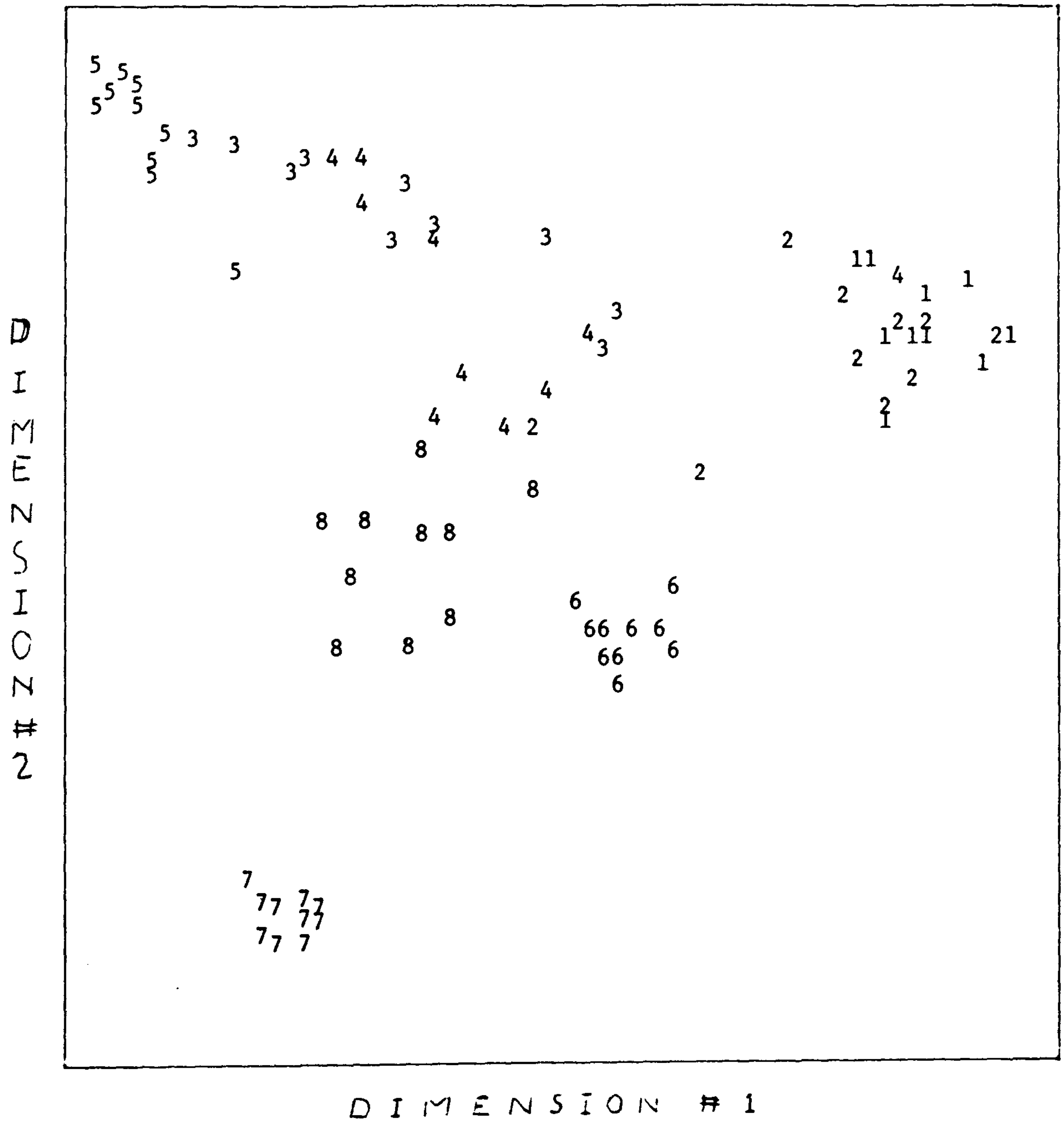
Appendix R. Similarity matrix yeilded by subjects' categorizations of analogies in the sorting task.

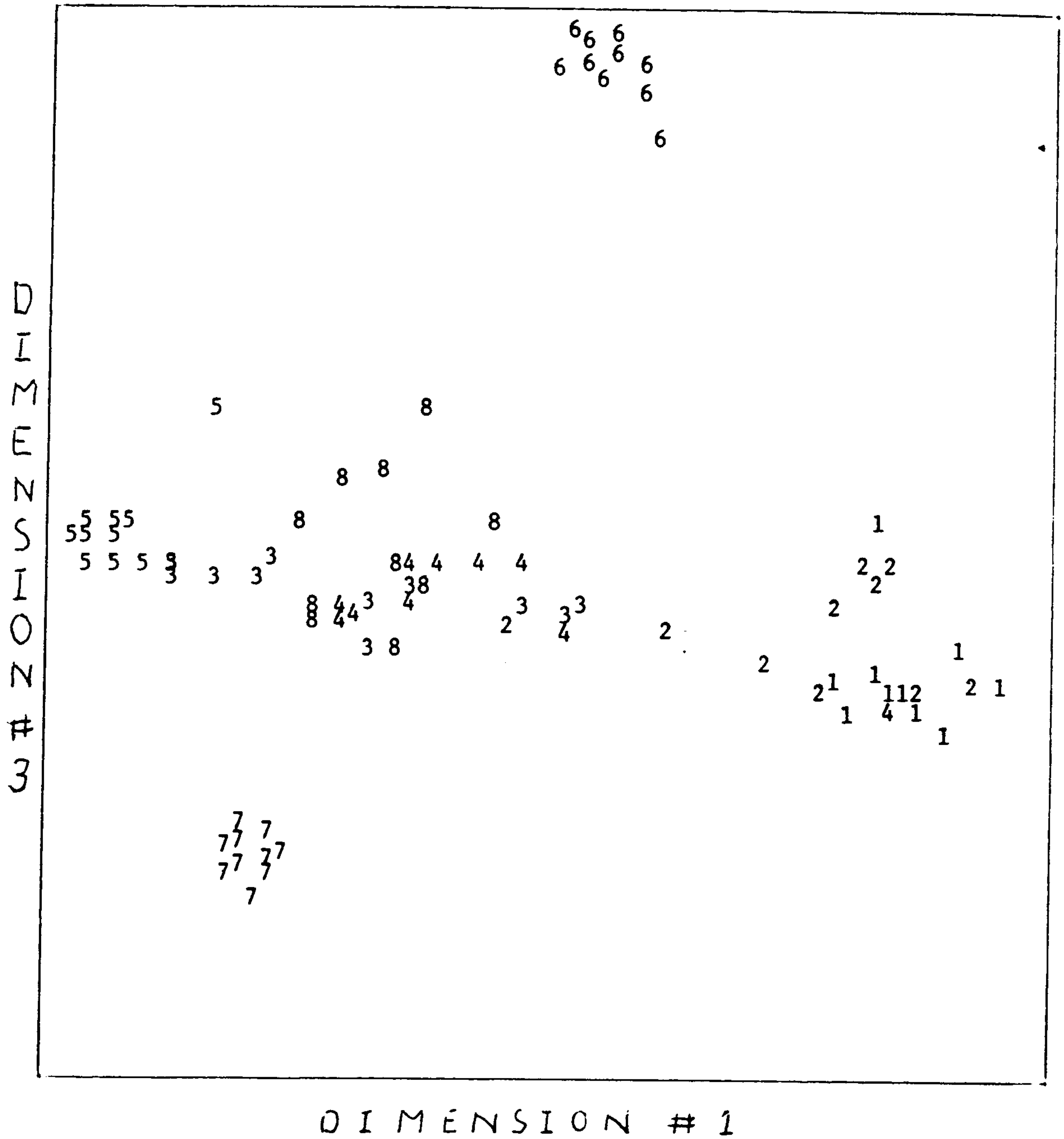
Appendix R. Similarity matrix yeilded by subjects' categorizations of analogies in the sorting task (continued).

50 01 02 02 02 03 06 01 01 02 01 01 03 02 03 02 04 01 02 02 01 01 01 01 01 01 01 01 01 01 02 01 02 01 02 02 01 01 02 01 01
02 04 02 02 01 01 02 02 01 02
51 02 01 04 02 05 06 02 03 03 02 00 05 03 05 02 05 02 04 03 02 01 01 00 01 00 00 00 00 00 01 01 02 00 00 02 00 00 03 01 00
00 03 01 01 00 00 00 01 00 01 22
52 01 01 03 01 04 05 01 02 02 01 00 04 02 04 01 04 01 03 02 01 01 01 00 00 00 00 00 00 00 01 01 02 00 00 01 00 00 02 01 00
00 03 01 01 00 00 00 01 00 01 22 23
53 01 01 03 01 04 05 01 02 02 01 00 04 02 04 01 04 02 03 02 01 01 01 00 00 00 00 00 00 00 01 01 02 00 00 01 00 00 02 01 00
00 03 00 00 00 00 00 01 00 00 21 22 23
54 01 01 03 01 04 05 01 02 01 01 00 04 02 04 01 04 01 03 02 01 01 01 00 00 00 00 00 00 00 01 01 02 00 00 01 00 00 02 01 00
00 03 01 01 00 00 00 01 00 01 21 22 23 23
55 01 01 03 01 04 05 01 02 02 01 00 04 02 04 01 04 01 03 02 01 01 01 00 00 00 00 00 00 00 01 01 02 00 00 01 00 00 02 01 00
00 03 01 01 00 00 00 01 00 01 22 23 24 24 24
56 01 01 02 01 03 05 02 01 03 02 01 03 02 03 01 05 02 02 03 01 00 00 00 00 00 01 00 01 00 01 00 01 00 00 01 01 01 02 00 00
01 03 01 01 00 00 01 01 00 01 23 22 23 23 22 23
57 02 01 04 02 05 06 02 03 02 02 00 05 03 05 02 05 02 04 03 02 01 01 00 01 00 00 00 00 00 01 01 02 00 00 02 00 00 04 01 00
00 03 01 01 00 00 00 01 00 01 21 23 22 22 22 22 21
58 01 01 03 01 04 05 01 02 01 01 00 04 02 04 01 04 01 03 02 01 01 01 00 00 00 00 00 00 00 01 01 02 00 00 01 01 00 02 01 00
00 03 01 01 00 00 00 02 00 01 21 22 23 23 23 23 22 22
59 03 03 04 03 03 05 02 03 05 04 03 04 02 05 01 07 03 04 05 01 00 01 01 01 00 02 00 01 00 01 01 02 00 01 03 02 02 02 00 00
01 03 01 01 00 00 01 00 00 01 21 20 21 21 20 21 21 18 20
60 00 00 00 00 00 00 00 00 00 00 02 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00
61 01 00 00 00 01 01 01 01 00 01 02 00 00 01 00 01 01 00 00 03 00 00 00 00 00 01 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 22
62 00 00 00 00 00 00 00 00 00 00 02 00 00 00 00 00 00 00 00 02 00 00 00 00 00 01 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 01 02 01 01 01 00 01 01 22 22
63 01 01 01 01 00 00 00 01 01 01 03 00 00 01 00 01 01 01 01 01 00 00 01 01 00 02 00 00 00 01 01 01 00 01 01 01 01 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 01 22 22 22
64 00 00 01 00 01 01 00 00 00 00 02 01 01 00 00 01 00 01 01 01 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 01 01 01 02 01 01 01 01 01 01 22 21 21 21
65 00 00 00 00 00 00 00 00 01 01 02 00 00 01 00 00 00 00 00 02 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 22 21 21 21 23
66 00 00 00 00 00 00 00 00 00 00 02 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 23 22 22 22 23 23
67 00 00 00 00 00 00 00 00 00 00 02 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 24 22 22 22 22 22 23
68 00 00 00 00 00 00 00 00 01 01 02 00 00 01 00 00 00 00 00 03 00 00 00 00 00 01 00 00 00 01 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 22 22 22 22 22 23 22 22
69 00 01 00 01 00 00 01 00 00 00 02 00 00 00 01 00 01 00 00 01 01 01 00 01 01 00 01 00 01 02 00 00 01 01 01 00 00 00 01 01
01 00 01 01 01 01 01 01 01 01 00 00 00 01 00 00 00 00 00 00 23 21 21 21 22 22 22 23 22
70 02 03 02 04 01 02 02 02 02 02 01 01 01 02 03 02 03 03 02 03 02 02 03 03 02 02 04 01 04 06 01 01 02 03 04 01 02 04 03 04
05 05 05 04 05 06 06 05 05 05 02 01 01 02 01 01 01 01 01 02 01 01 01 02 01 01 01 01 01 02
71 00 00 00 01 00 01 01 02 01 01 01 01 00 01 02 00 01 02 00 05 01 01 01 02 01 00 01 01 02 01 01 01 01 01 01 02 00 01 01 02
02 03 02 02 02 03 01 01 02 02 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 01 00 01 01 01 15
72 00 00 00 00 00 00 02 00 01 01 03 02 00 01 01 02 02 01 01 02 01 01 00 01 01 01 01 02 01 01 02 02 01 00 00 03 01 01 01 02
01 04 01 01 01 03 01 00 01 01 07 07 07 08 07 07 08 07 07 08 00 00 00 00 00 00 00 00 00 00 10 14
73 02 02 02 02 01 01 01 04 03 02 02 01 01 03 01 02 02 02 02 05 00 00 02 02 00 02 00 00 01 01 03 04 00 02 02 05 01 04 00 02
01 01 02 02 03 01 01 03 02 02 00 00 00 01 00 00 00 00 00 01 01 01 01 02 01 02 01 01 02 00 14 16 10
74 01 01 01 01 01 02 02 02 04 04 02 01 01 03 01 02 03 02 02 07 00 00 01 00 00 02 00 01 01 01 02 00 00 00 01 02 01 04 00 01
01 00 00 00 01 01 00 01 01 00 01 01 01 01 01 01 02 02 01 02 02 02 02 01 02 03 02 02 03 02 11 13 10 13
75 00 00 00 00 00 00 01 01 02 02 02 00 00 01 00 01 02 02 01 05 00 00 01 01 00 01 00 01 01 00 03 01 00 00 00 02 01 02 00 02
01 00 00 00 01 01 00 01 01 00 00 00 00 01 00 00 01 00 00 01 02 02 02 01 02 03 02 02 03 02 12 16 11 15 20
76 00 00 00 01 00 02 00 01 01 01 01 01 00 02 01 01 01 01 00 08 00 00 00 02 00 00 00 00 00 00 02 01 00 01 01 01 00 02 00 01
01 00 01 01 00 00 01 00 00 01 04 03 03 02 03 03 03 04 03 03 02 02 02 01 02 03 02 02 03 02 11 15 10 13 18 19
77 01 00 00 00 00 00 01 00 01 00 02 01 00 00 02 00 01 02 00 03 02 02 02 02 01 00 04 04 03 02 03 01 02 00 00 02 02 03 03 03
02 04 04 05 03 02 02 02 02 04 02 02 02 01 02 02 02 02 02 02 01 01 01 01 01 01 01 01 01 01 11 15 12 15 11 14 14
78 00 02 00 00 00 01 00 01 01 02 03 00 00 02 00 00 01 01 00 05 01 01 01 02 01 02 01 01 01 01 03 03 01 02 00 03 01 03 01 02
01 01 02 02 02 01 01 02 01 02 01 00 00 00 00 00 00 01 00 00 02 02 02 01 02 03 02 02 03 02 10 14 10 15 18 19 19 15
79 04 04 04 04 03 03 03 06 05 04 01 03 03 05 03 04 03 04 04 05 01 01 02 02 01 03 00 01 01 02 03 04 01 04 04 05 01 06 01 03
01 01 02 02 03 01 01 03 02 02 02 02 02 03 02 02 02 02 02 02 00 00 00 01 00 01 00 00 01 00 13 13 08 20 11 12 09 12 11



8	MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
7	O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
5	SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
6	SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
3	P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
4	SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
1	W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
2	SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

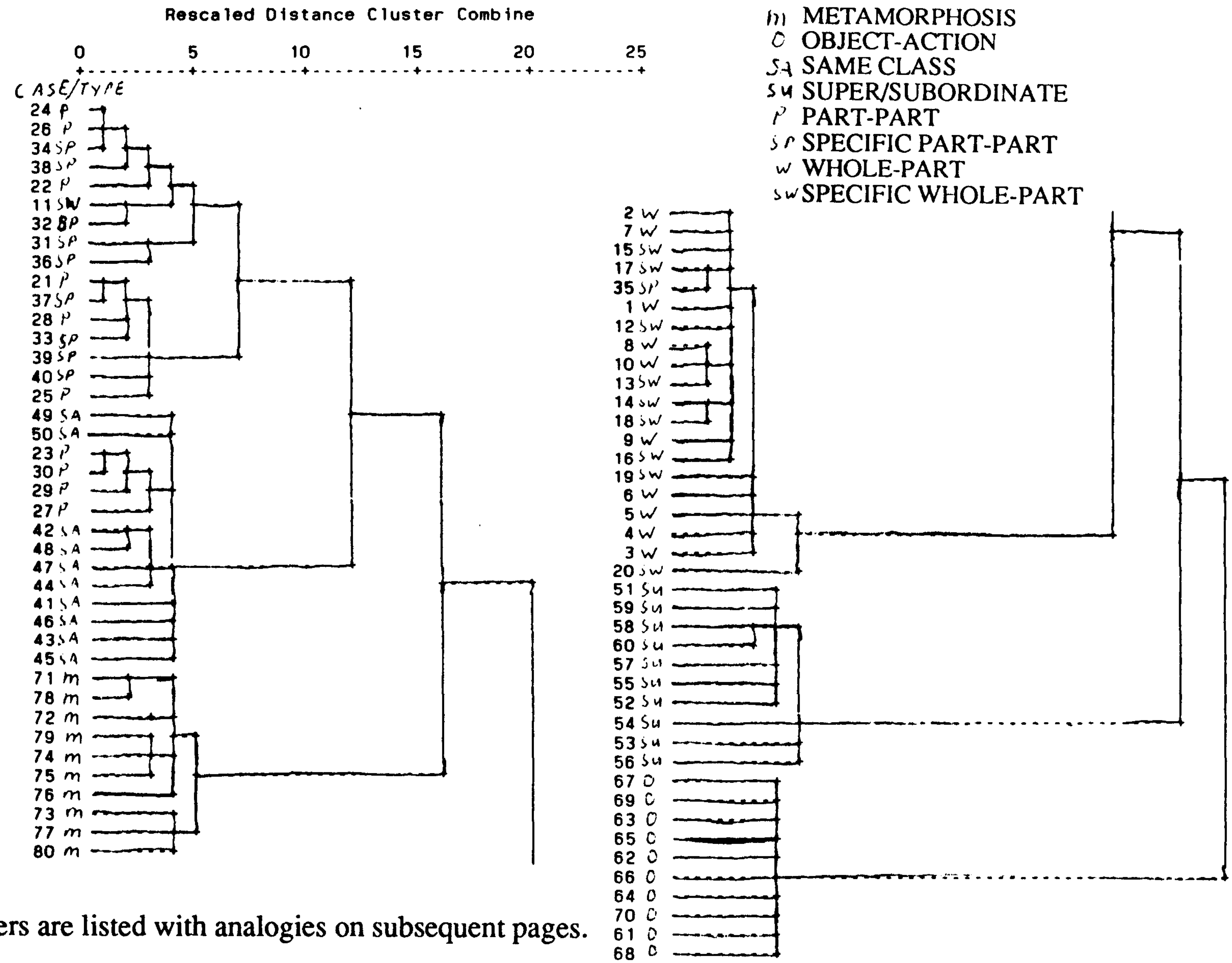
Appendix S. Plots for the three dimensional scaling solution of similarity data from sorting task.



8	MET	METAMORPHOSIS	GIRL : WOMAN AS BOY : MAN
7	O-A	OBJECT-ACTION	RABBIT : HOP AS WHALE : SWIM
5	SAC	SAME CLASS	ORANGE : APPLE AS CARROT : CORN
6	SUP	SUPER/SUBORDINATE	FRUIT : APPLE AS VEGETABLE : CORN
3	P-P	PART-PART	BUMPER : WHEELS AS HULL : MAST
4	SPP	SPECIFIC PART-PART	HAND : ELBOW AS FOOT : KNEE
1	W-P	WHOLE-PART	CAR : WHEELS AS BOAT : MAST
2	SWP	SPECIFIC WHOLE-PART	HAND : PALM AS FOOT : SOLE

Appendix S. Plots for the three dimensional scaling solution of similarity data from sorting task (continued).

Appendix T. Full dendrogram for cluster analysis of similarity data from sorting task.



note. case numbers are listed with analogies on subsequent pages.

Whole-Part	
1. book : spine	pencil : lead
2. elevator : door	escalator : stairs
3. brush : bristles	cigarette : filter
4. teapot : spout	clock : hands
5. school : gym	restaurant : kitchen
6. orchestra : violins	choir : soprano
7. chair : leg	door : handle
8. highway : median	river : bank
9. tree : leaf	flower : petal
10. desert : tumbleweed	beach : sand
Specific Whole-Part	
11. pool cue : chalk	skis : wax
12. book : chapter	play : act
13. chair : legs	car : wheels
14. library : book	pharmacy : drug
15. foot : sole	hand : palm
16. team : player	army : soldier
17. snake : skin	rabbit : fur
18. apple : core	peach : pit
19. organ : keys	guitar : strings
20. volcano : lava	chimney : smoke
Part-Part	
21. floor : door	chimney : roof
22. bumper : headlight	sail : mast
23. knife : fork	saucer : plate
24. wax : wick	lampshade : bulb
25. beak : wing	paw : tail
26. rail : ties	spokes : hub
27. toilet : tub	stove : fridge
28. neck : leg	roots : branches
29. ear : eye	stomach : kidney
30. balance beam : trampoline	swingset : slide

Appendix T. Full dendrogram for cluster analysis of similarity data from sorting task (continued).

Specific Part-Part

31. gravy : meat	dressing : salad
32. tobacco : pipe	coffee : cup
33. lungs : skin	gills : scales
34. blossom : stem	flag : pole
35. helmet : visor	eye : lid
36. puck : rink	ball : field
37. stern : bow	caboose : engine
38. acorn : leaf	pinecone : needle
39. arm : leg	flipper : fin
40. hand : elbow	foot : knee

Same Class

41. pork : beef	shrimp : scallops
42. doctor : engineer	plumber : electrician
43. ant : mosquito	lizard : snake
44. Latin : French	New Zealand : Peru
45. apple : cherry	potato : carrot
46. wrench : screwdriver	flute : clarinet
47. pants : shirt	necklace : ear-ring
48. tennis : golf	gin rummy : poker
49. chair : bed	dishwasher : stove
50. daisy : tulip	pine : oak

Super/Subordinate

51. reptile : turtle	insect : ant
52. hobby : model-building	pet : dog
53. animal : bear	bird : crow
54. professional : lawyer	tradesman : welder
55. meat : bacon	seafood : lobster
56. clothing : sweater	jewelery : ring
57. fruit : banana	vegetable : corn
58. furniture : table	appliance : stove
59. sport : soccer	game : monopoly
60. flower : rose	tree : maple

Appendix T. Full dendrogram for cluster analysis of similarity data from sorting task (continued).

Object-Action	
61. lovers : kiss	mourners : cry
62. plaster : crack	stocking : run
63. elastic : stretch	glue : stick
64. potato : bake	bacon : fry
65. nose : smell	eyes : see
66. hammer : pound	knife : cut
67. airplane : fly	ship : sail
68. lamp : shine	alarm : ring
69. lion : roar	pig : squeal
70. rabbit : hop	whale : swim
Metamorphosis	
71. plum : prune	grape : raisin
72. catterpillar : butterfly	tadpole : frog
73. apprentice : carpenter	intern : doctor
74. seedling : tree	bud : flower
75. cow : hamburger	pig : bacon
76. barley : beer	grapes : wine
77. clay : pottery	dough : bread
78. water : ice	rain : snow
79. sand : cement	pulp : paper
80. acorn : oak	bulb : tulip

Appendix T. Full dendrogram for cluster analysis of similarity data from sorting task (continued).

EXPERIMENT 1

Experiment 1, 2 X 2 ANOVA on top tier analogy types, recognition data

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	4578103.0	23		
Specificity(A)	11145600.0	1	31.9	.001
AXS-W	349862.9	23		
Inclusiveness(B)	11362176.0	1	30.6	.001
BXS-W	370877.2	23		
AXB	292992.0	1	1.2	.288
AXBXS-W	247373.9	23		

Items Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Specificity(A)	5169601.0	1	13.9	.001
Inclusiveness(B)	4919521.0	1	13.2	.001
AXB	561760.1	1	1.5	.227
Subjects-within	371434.6	36		

Experiment 1, 2 X 2 ANOVA on top tier analogy types, recall data

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	5976954.0	23		
Specificity(A)	40117632.0	1	33.6	.001
AXS-W	1195430.0	23		
Inclusiveness(B)	35859456.0	1	35.7	.001
BXS-W	1003809.4	23		
AXB	1676544.0	1	2.0	.166
AXBXS-W	820535.6	23		

Judges Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	5682476.0	23		
Specificity(A)	36271488.0	1	30.0	.001
AXS-W	1209444.0	23		
Inclusiveness(B)	34367232.0	1	35.7	.001
BXS-W	962671.3	23		
AXB	2578944.0	1	2.9	.102
AXBXS-W	888553.7	23		

Items Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Specificity(A)	10064162.0	1	13.6	.001
Inclusiveness(B)	17400160.0	1	23.5	.001
AXB	1439520.0	1	1.9	.171
Subjects-within	739264.0	36		

Experiment 1, 2 X 3 ANOVA on front face analogy types, recognition data

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	5527540.0	23		
Funct/struct(A)	9634398.0	2	16.0	.001
AXS-W	603937.4	46		
Inclusiveness(B)	11521536.0	1	19.4	.001
BXS-W	593819.8	23		
AXB	198336.0	2	1.4	.266
AXBXS-W	145474.8	46		

Experiment 1, 2 X 3 ANOVA on front face analogy types, recall data

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects(S-W)	9158500.0	23		
Funct/struct(A)	49379328.0	2	38.0	.001
AXS-W	1297997.0	46		
Inclusiveness(B)	29620992.0	1	89.5	.001
BXS-W	331019.1	23		
AXB	381504.0	2	0.6	.552
AXBXS-W	633672.3	46		

Judges Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects(S-W)	8822071.0	23		
Funct/struct(A)	46876032.0	2	39.5	.001
AXS-W	1185485.0	46		
Inclusiveness(B)	27706368.0	1	82.0	.001
BXS-W	337741.9	23		
AXB	395136.0	2	0.6	.554
AXBXS-W	661136.7	46		

Experiment 1, 2 X 2 X 2 ANOVA comparing two paradigms on top tier analogy types

Source	Mean Squares	Degrees of freedom	F ratio	probability
Paradigms(A)	12598272.0	1	2.4	.129
Subjects(S-W)	5277523.0	46		
Specificity(B)	46777728.0	1	60.5	.001
AXB	4485888.0	1	5.8	.02
BXS-W	772646.9	46		
Inclusiveness(C)	43796352.0	1	63.7	.001
AXC	3425280.0	1	5.0	.031
CXS-W	687343.3	46		
BXC	1684992.0	1	3.2	.082
AXBXC	284160.0	1	.5	.469
BXCXS-W	533960.3	46		

Appendix Z. ANOVA tables for analyses cited in thesis (continued).

Experiment 1, 2 X 2 X 3 ANOVA comparing two paradigms on front face analogy types

Source	Mean Squares	Degrees of freedom	F ratio	probability
Paradigms(A)	16148352.0	1	2.2	.147
Subjects(S-W)	7405211.0	46		
Funct/struct(B)	49408704.0	2	52.3	.001
AXB	8233152.0	2	8.7	.001
BXS-W	945152.0	92		
Inclusiveness(C)	39286656.0	1	84.8	.001
AXC	2153856.0	1	4.7	.036
CXS-W	463204.1	46		
BXC	534528.0	2	1.4	.262
AXBXC	13824.0	2	.04	.965
BXCXS-W	392993.4	92		

EXPERIMENT TWO

Priming Experiment, 2 X 2 X 2 ANOVA testing primingon top tier analogy types, recognition data

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&2(A)	1099392.0	1	0.2	.636
Subjects(S-W)	4848729.0	46		
Specificity(B)	19630464.0	1	52.2	.001
AXB	84864.0	1	0.2	.637
BXS-W	376136.3	46		
Inclusiveness(C)	21692544.0	1	49.9	.001
AXC	12288.0	1	0.03	.867
CXS-W	434437.6	46		
BXC	1587840.0	1	7.1	.011
AXBXC	243840.0	1	1.1	.302
BXCXS-W	223760.7	46		

Priming Experiment, 2 X 2 X 2 ANOVA testing primingon top tier analogy types, recall data

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&2 (A)	1064448.0	1	0.2	.648
Subjects(S-W)	5041669.0	46		
Specificity(B)	86622336.0	1	84.6	.001
AXB	122112.0	1	0.1	.731
BXS-W	1023888.7	46		
Inclusiveness(C)	83304192.0	1	66.7	.001
AXC	433536.0	1	0.3	.559
CXS-W	1249335.0	46		
BXC	4364160.0	1	4.3	.043
AXBXC	66816.0	1	0.1	.798
BXCXS-W	1004109.9	46		

Priming Experiment, 2 X 3 X 2 ANOVA testing priming
on front face analogy types, recognition data

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&2(A)	332160.0	1	0.05	.820
Subjects(S-W)	6309353.0	46		
Funct/struct(B)	24403776.0	2	43.6	.001
AXB	647424.0	2	1.2	.319
BXS-W	559326.6	92		
Inclusiveness(C)	18643200.0	1	27.4	.001
AXC	233088.0	1	0.3	.561
CXS-W	681093.6	46		
BXC	1217664.0	2	5.6	.005
AXBXC	239808.0	2	1.1	.335
BXCXS-W	216909.9	92		

Priming Experiment, 2 X 3 X 2 ANOVA testing priming
on front face analogy types, recall data

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&2(A)	7279104.0	1	1.0	.334
Subjects(S-W)	7630313.0	46		
Funct/struct(B)	99763968.0	2	101.0	.001
AXB	1377216.0	2	1.4	.253
BXS-W	987581.2	92		
Inclusiveness(C)	68287488.0	1	77.8	.001
AXC	278784.0	1	0.3	.576
CXS-W	878235.8	46		
BXC	2842560.0	2	4.0	.022
AXBXC	746112.0	2	1.0	.358
BXCXS-W	717378.8	92		

Appendix Z. ANOVA tables for analyses cited in thesis (continued).

Analysis of Priming Experiment as a Replication of Experiment 1

Priming Experiment (Exp't 2), 2 X 2 ANOVA on top tier analogy types, recognition data.

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	5119376.0	23		
Specificity(A)	8569344.0	1	21.3	.001
AXS-W	402398.6	23		
Inclusiveness(B)	10342272.0	1	20.8	.001
BXS-W	497986.8	23		
AXB	1539456.0	1	7.7	.011
AXBXS-W	200169.7	23		

Items Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Specificity(A)	1877440.0	1	4.2	.049
Inclusiveness(B)	6231521.0	1	13.8	.001
AXB	677600.2	1	1.5	.229
Subjects-within	451562.6	36		

Priming Experiment (Exp't 2), 2 X 2 ANOVA on top tier analogy types, recall data

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	4167245.0	23		
Specificity(A)	47638272.0	1	58.1	.001
AXS-W	819979.1	23		
Inclusiveness(B)	48410880.0	1	33.0	.001
BXS-W	1465210.0	23		
AXB	2883456.0	1	2.5	.130
AXBXS-W	1167037.0	23		

Judges Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	4290949.0	23		
Specificity(A)	47975424.0	1	58.2	.001
AXS-W	823997.2	23		
Inclusiveness(B)	47608704.0	1	33.7	.001
BXS-W	1411795.0	23		
AXB	2466816.0	1	2.1	.157
AXBXS-W	1152289.0	23		

Items Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Specificity(A)	13341443.0	1	12.7	.001
Inclusiveness(B)	23066080.0	1	22.0	.001
AXB	2375040.0	1	2.3	.141
Subjects-within	1047985.8	36		

Priming Experiment, 2 X 3 ANOVA on front face analogy types, recognition data

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects-within(S-W)	7091511.0	23		
Funct/struct(A)	15416832.0	2	30.0	.001
AXS-W	514765.9	46		
Inclusiveness(B)	7354752.0	1	9.6	.005
BXS-W	768178.1	23		
AXB	1258944.0	2	4.4	.018
AXBXS-W	288517.6	46		

Priming Experiment, 2 X 3 ANOVA on front face analogy types, recall data

Subjects Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects(S-W)	5928848.0	23		
Funct/struct(A)	54994176.0	2	78.3	.001
AXS-W	702502.9	46		
Inclusiveness(B)	40247040.0	1	28.0	.001
BXS-W	1439243.0	23		
AXB	2726592.0	2	3.6	.036
AXBXS-W	760108.5	46		

Appendix Z. ANOVA tables for analyses cited in thesis (continued).

Judges Analysis

Source	Mean Squares	Degrees of freedom	F ratio	probability
Subjects(S-W)	6012672.0	23		
Funct/struct(A)	55933824.0	2	75.4	.001
AXS-W	742316.5	46		
Inclusiveness(B)	41587200.0	1	29.6	.001
BXS-W	1405028.0	23		
AXB	2557440.0	2	3.4	.043
AXBXS-W	759685.6	46		

Priming Experiment, 2 X 2 X 2 ANOVA comparing two paradigms on top tier analogy types

Source	Mean Squares	Degrees of freedom	F ratio	probability
Paradigms(A)	2008320.0	1	0.4	.514
Subjects(S-W)	4643311.0	46		
Specificity(B)	48308352.0	1	79.0	.001
AXB	7899264.0	1	12.9	.001
BXS-W	611183.3	46		
Inclusiveness(C)	51752448.0	1	52.7	.001
AXC	7000704.0	1	7.1	.01
CXS-W	981593.0	46		
BXC	4318464.0	1	6.3	.016
AXBXC	104064.0	1	0.2	.698
BXCXS-W	683614.6	46		

Priming Experiment, 2 X 2 X 3 ANOVA comparing two paradigms on front face analogy types

Source	Mean Squares	Degrees of freedom	F ratio	probability
Paradigms(A)	2976000.0	1	0.5	.502
Subjects(S-W)	6509879.0	46		
Funct/struct(B)	63135552.0	2	103.7	.001
AXB	7275456.0	2	12.0	.001
BXS-W	608656.7	92		
Inclusiveness(C)	41005824.0	1	37.1	.001
AXC	6595968.0	1	6.0	.018
CXS-W	1103872.0	46		
BXC	3821952.0	2	7.3	.001
AXBXC	163776.0	2	0.3	.732
BXCXS-W	524243.4	92		

Appendix Z. ANOVA tables for analyses cited in thesis (continued).

EXPERIMENT 3

Reordering Experiment, 2 X 2 X 2 ANOVA testing reordering
on top tier analogy types, recognition paradigm

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&3(A)	28099968.0	1	3.2	.079
Subjects(S-W)	8700488.0	46		
Specificity(B)	32163840.0	1	54.5	.001
AXB	902400.0	1	1.5	.223
BXS-W	590386.1	46		
Inclusiveness(C)	14389248.0	1	21.2	.001
AXC	948096.0	1	1.4	.243
CXS-W	679223.6	46		
BXC	4061184.0	1	7.5	.009
AXBXC	1562880.0	1	2.9	.097
BXCXS-W	543254.3	46		

Reordering Experiment, 2 X 2 X 2 ANOVA testing reordering
on top tier analogy types, recall paradigm

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&3(A)	32218752.0	1	4.1	.049
Subjects(S-W)	7878745.0	46		
Specificity(B)	65661696.0	1	31.0	.001
AXB	729600.0	1	0.3	.56
BXS-W	2116474.0	46		
Inclusiveness(C)	112010112.0	1	97.0	.001
AXC	4472064.0	1	3.9	.055
CXS-W	1154448.0	46		
BXC	72960.0	1	0.1	.823
AXBXC	4416384.0	1	3.1	.087
BXCXS-W	1447936.0	46		

Appendix Z. ANOVA tables for analyses cited in thesis (continued).

Reordering Experiment, 2 X 3 X 2 ANOVA testing reordering on front face analogy types, recognition paradigm

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&3(A)	20832768.0	1	2.3	.137
Subjects(S-W)	9081811.0	46		
Funct/struct(B)	29922624.0	2	38.1	.001
AXB	3521472.0	2	4.5	.014
BXS-W	784562.1	92		
Inclusiveness(C)	12129024.0	1	21.8	.001
AXC	1736448.0	1	3.0	.091
CXS-W	583769.0	46		
BXC	1925760.0	2	4.2	.018
AXBXC	850176.0	2	1.8	.164
BXCXS-W	461423.3	92		

Reordering Experiment, 2 X 3 X 2 ANOVA testing reordering on front face analogy types, recall paradigm

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&3(A)	34418688.0	1	2.9	.098
Subjects(S-W)	12040102.0	46		
Funct/struct(B)	63049728.0	2	29.9	.001
AXB	8644608.0	2	4.1	.02
BXS-W	2111621.0	92		
Inclusiveness(C)	141434880.0	1	76.9	.001
AXC	17289216.0	1	9.4	.004
CXS-W	1838569.0	46		
BXC	3883008.0	2	2.7	.075
AXBXC	1308672.0	2	0.9	.411
BXCXS-W	1457775.0	92		

Appendix Z. ANOVA tables for analyses cited in thesis (continued).

EXPERIMENT 4

Specificity Experiment, 2 X 2 X 2 ANOVA testing specificity, inclusiveness, and two lists of stimulus set

Source	Mean Squares	Degrees of freedom	F ratio	probability
Lists(A)	19901760.0	1	3.2	.087
Subjects(S-W)	6183133.0	22		
Inclusiveness (B)	7872961.0	1	5.0	.035
AXB	5491393.0	1	3.5	.075
BXS-W	1567290.0	22		
Specificity (C)	30677184.0	1	13.3	.001
AXC	2027712.0	1	0.9	.358
CXS-W	2300602.0	22		
BXC	3270144.0	1	4.5	.046
AXBXC	8832.0	1	.01	.913
BXCXS-W	730042.1	22		

EXPERIMENT 5

Realm Switching Experiment, 2 X 3 X 2 ANOVA testing realm switching on front face analogy types, recognition paradigm

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&5(A)	22486656.0	1	2.3	.136
Subjects(S-W)	9770028.0	46		
Funct/struct(B)	10193856.0	2	20.4	.001
AXB	2960064.0	2	5.9	.004
BXS-W	499133.2	92		
Inclusiveness(C)	15252096.0	1	33.0	.001
AXC	800640.0	1	1.7	.195
CXS-W	462313.7	46		
BXC	9600.0	2	.05	.953
AXBXC	529152.0	2	2.7	.074
BXCXS-W	197320.3	92		

Realm Switching Experiment, 2 X 3 X 2 ANOVA testing realm switching on front face analogy types, recall paradigm

Source	Mean Squares	Degrees of freedom	F ratio	probability
Experiments 1&5(A)	13181184.0	1	0.7	.429
Subjects(S-W)	20696992.0	46		
Funct/struct(B)	53671680.0	2	20.5	.001
AXB	7555008.0	2	2.9	.061
BXS-W	2624601.0	92		
Inclusiveness(C)	86677248.0	1	45.6	.001
AXC	2602368.0	1	1.4	.248
CXS-W	1900900.0	46		
BXC	857856.0	2	0.6	.543
AXBXC	320256.0	2	0.2	.795
BXCXS-W	1395756.0	92		

Appendix Z. ANOVA tables for analyses cited in thesis (continued).