Human Text Processing and Models of Knowledge Representation

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Abstract

Two experimental studies on human text processing and knowledge representation are reported. They are designed to explore the nature of cognitive processes in working memory and long term representations associated with the resolution of reference in texts. Resolution of references occurs when properties of distinct individuals are bound together in memory. Stenning Shepherd and Levy (1988) propose that binding is achieved by recruiting existing general knowledge associations based on the semantic structure of texts. They present models of representation structures employed in a novel Memory for Individual Task (MIT), and show that these models can explain certain patterns of retrieval error frequencies. A statistical model of construction of representation processes which account for a particular pattern of reading times in terms of key aspects of the structure of MIT texts is also presented.

The reading times results of the first MIT experiment, in which the order of switches in reference between individuals is unpredictable, is presented together with as extended construction processing model which capture phenomena of reference changes. The new models show that unpredictable reference changes cost time as a function of the complexity of the individual to which reference is switched, without disrupting the modular account of processing centred on referenced individual reported by Stenning, Shepherd and Levy (1988). Analysis of recall errors reveal an effect of presentation order, which results in confusion over identity of individuals' properties, providing a basis for a distinction between 'primary' and 'secondary' individual, each requiring different syllabic rehearsal processing. These working memory processes are incorporated in a model, which reveals interaction between rehearsal and semantic processes.

The error data is further analysed with respect to logically constraining solutions to representations of bindings with 'direct' and 'indirect' structures. Direct systems represent binding by structural devices referring to individual identities in their representation; indirect systems represent binding only through quantificational facts. Both direct and indirect models are developed and the latter one shown to be at least as good a fit to the data as the former, which suggests that solution to the binding problem is represented in a distributed manner closer to PDP systems.

Much of the theoretical underpinning of the findings of the first study, is dependent on aspects of the semantic structures which reflect regularities in the temporal order of descriptions of individuals in MIT texts. The second study investigates the extent to which such regularities facilitated the sorts of structures constructed in representations of solutions to the binding problem, and interaction between temporal order of presentation and working memory processes. Analyses of reading times show that, while order of presentation of properties has no significant effect on working memory processes, differences in availability of information about higher level semantic structure does require extra processing. A statistical model which factors out some of this processing load as due to specific changes in the semantic structure of MIT texts is presented.

Detailed analyses of recall error data further reveals differences in indirect representational features which reflect changes in temporal order of individuals' descriptions. These models show how texts with the same literal meaning obtain significantly different representations in memory, not because of different contexts which would be expected, but due to differences in temporal order of the *same* sorts of descriptions. This suggests that the theoretical distinction between working memory processes and long term representations is not as simple as it might appear. These findings also serve to support our methodological approach to the study of human text processing.

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DECLARATION

I declare that this thesis has been composed by myself, and that the work presented herein is my own.

Mukesh Jayantilal Patel

To my Mother and Father,
and,
all their grandchildren

Contents

Chapter 1:

Chapter 2:

Chapter 3:

Chapter 4:

Chapter 5:

Chapter 6:

Chapter 7:

Appendices:

Chapter 1

1. Introduction

The overall aim of this thesis is to investigate how text processing occurs in human memory, and, to model this behaviour in terms of the effect of higher level, non-lexical, text semantics on processing and representation. Human text comprehension is characterised as a process of construction of representation of the semantic structure of written texts. Semantic structure refers to individuals, their properties and relations described in a text. Text comprehension can occur at a number of different levels depending on, amongst other things, context. Due to the complexity it would be difficult to address all levels simultaneously in the sort of investigation reported here. Hence, our modest aim is to present models of both, cognitive processes involved in the construction of texts, and, the nature of the representation structures which capture one particular aspect of text semantics. The studies reported here will help describe the relationship between construction processes and representations, which as will be shown is largely dependent on our distinctive methodological approach to the investigation of text comprehension from two distinct but related perspectives (facilitated by detailed analysis of reading time and recall error data).

The first allows us to look at the dynamic process of comprehension; how a representation is built up, and how the processes can be described in terms of the semantic structure of texts. This approach facilitates the development of models of general aspects of the relationship between cognitive processing load and semantic complexity of texts. The second perspective enables us to describe the nature of the obtained representations. How is the information contained in a text represented so as to be compatible with the intended meaning[1] of a text? The intention is to model the representation structures which

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[1] Here as elsewhere in this thesis it is assumed that at one level any text has a standard 'reading' which is treated as equivalent to its *meaning*.

captures the meaning of a text. While it is possible to develop models of representations for different levels of comprehension (eg, literal, metaphorical, etc), here the representation models are limited to compatibility with the (information) processing models. Both perspectives are useful in the exploration of text comprehension. The goal of our research approach is to develop and present cognitive models which are based on observed variance in descriptive data that reflect the effect of specific semantic structures on text comprehension. We will also explain how this goal is achieved by our methodological approach; a combination of our novel experimental paradigm, Memory for Individual Task (MIT), and more sophisticated application of analytical tools.

2. The binding problem in human memory

In this section I describe specific aspects of text comprehension and knowledge representation that will concern us for the rest of this thesis. Take for example, the following simple (MIT) text:

> There is a chef. The chef is sane. The chef is Swiss. The chef is old.
>
> There is a vet. The vet is mad. The vet is Swiss. The vet is young.

How are the properties "chef", "sane" and "Swiss" and "old" represented as belonging to one and the same individual? How are they bound together? This is an interesting question since the manner in which this information is encoded and subsequently retrieved is crucially dependent on what cognitive processing is involved in the construction of the higher level semantic structures, and the manner in which they are organised (that is, what sorts of features in the representation capture the associations between properties of one individual). In the example above, the semantic structures constitute the descriptions of two individuals each with four property attributes, and the relational structure that determines the assignment of properties to a particular individual. We refer to this as the *attribute binding problem.* The resolution of reference, that is, the knowledge that the chef in the second sentence in the example above refers to the one mentioned in the first sentence is a specific instance of the binding problem, and one which will be considered in detail in this thesis.

The binding problem in knowledge representation has hitherto received limited attention in relevant research on episodic memory (cf. Wickelgren, 1977; Sanford and Garrod, 1981, for instance). Resolution of reference can be construed as a general case of resolution of anaphora which has received a lot more attention (Hankamer and Sag, 1976 & 1984; Grosz, Joshi and Weinstein, 1983; Webber 1978; Sidner 1979; Reinhart 1981; Marslen-Wilson, Levy and Tyler, 1981; Garrod and Sanford 1982; also see Hirst 1981 for a review). Anaphoric resolution occurs when a pronoun, for example, is resolved in terms of a referent mentioned in the (usually) preceding part of a text (Chafe 1976; Halliday 1973).

The importance of associations between properties which capture the implicit relationship between a set of properties belonging to one individual has been stressed by, among others, Stenning (1978, 1986) and Johnson-Laird (1983). As for anaphoric reference resolution, in the present (more general) case, a reader represents the fact that it is the same "chef" who is both "sane" and "Swiss" with the aid of contextual information (eg, Miller 1959). The resolution of the binding problem is further facilitated by writers sticking to conventions such as temporal order, consistency, constant naming, etc (Li 1976, Bruner 1986, Barclay, Bransford, Franks, McCarrell and Nitch 1974). The efficiency of such conventions is to limited extent dependent on the number of logically possible resolutions that can be instantiated which determines the potential for ambiguity. Ideally there is only one possible resolution (that is, unambiguous), and as Johnson-Laird (1983) shows when there are more than one possible resolutions (or in his terminology, more than one mental model) it can lead to complications and even breakdown in understanding.

Investigating solutions to the nature of the binding problem, which is a central part of human cognitive processing, do not only provide a better understanding of the nature of text comprehension and representational processes but it also provides, as we intend to show, a deeper understanding of the role of working memory during comprehension and long term memory during subsequent recall. However, apart from some recent work (Stenning, Patel and Levy 1987; Stenning, Shepherd and Levy 1988, and other experimental studies yet to be published) there has been little investigation into how bindings between attributes are either mapped on to the relevant individual or represented and manipulated in working memory. One of the main reasons for this neglect is that resolution of anaphoric reference is perceived as a more important problem since it more obviously requires access to a great deal of contextual knowledge which has proved to be difficult to implement on a machine (Bobrow and Winograd 1977 is a good exemplar of such difficulties; see also Bobrow et al 1977). Whereas the binding problem has been very simple to implement on conventional computers where usually a link is set up by a pointer between relevant attributes to represent bindings between referents and properties. Of course, the same mechanism can also be used for reference resolution (Carpenter 1989).

Work on text grammars and discourse analysis (eg, Sanford and Garrod, 1981; Sanford 1987; and for a more theoretical and formal approach see Burghardt and Holker 1979) do not consider this issue since it also invariabely concentrates on describing the sorts of contextual knowledge required for reference resolution. How the resolved reference is represented with a binding is not addressed. Where it has cropped up, it is typically represented by a primitive unanalysable link as for example in cognitive process models HAM (Bower and Anderson 1973) and ACT (Anderson 1983). Johnson-Laird (summarised in 1983) too, though recognising the problem, does not attempt to account for it. Issues about representation in memory based on list learning tasks also fail to address the binding problem (eg, Miller 1956; Tulving 1983; Baddeley, Thomson & Buchanan 1975).

For human beings, however, the problem is not reference resolution (such as anaphora), which is effortless, but the representation of binding between attributes of an individual. Confusion between individuals with similar combinations of attributes provides evidence for such difficulties (Miller and Nicely 1955 and Conrad 1964 are examples of studies on this sort of confusion to which we will return to in Chapters 5 and 6). For the resolution of the binding problem we rely on content (that is, lexical items themselves) as well as the richness of general knowledge which facilitates the representation of distinguishing structures associated with individuals. The resolution of the binding problem is also aided by the format (or form, as it is usually referred to in discourse analysis literature) of texts which as the findings presented here will show is crucial in determining the sorts of higher level semantic structures that are encoded in representations resolved bindings. The high degree of constraint on our stimuli texts, such as the one given above, facilitates this sort of detailed investigation of specific aspect such as temporal order and format of texts on cognitive processing and representation structures. We will explain this methodological approach in greater detail after presenting the findings and the implications of a study by Stenning Shepherd and Levy (1988 - henceforth referred to as SSL) which supports the preceding outline of the binding problem, and which provides the main motivation for the first experimental study described in Chapters 2, 3 and 4.

2.1. Stenning Shepherd and Levy (SSL) study

Stenning (1976) and Stenning, Shepherd and Levy (1988) show that when presented with texts such as the one given in the previous section, readers do not ignore all associative links between attributes of individuals and simply represent the eight lexical items, as one might if given a simple list of attributes. The data from these studies do not show the usual serial position effect evident in list learning experiments, and interference during recall is weak (Baddeley 1986). They report that reading times of self-paced sentence by sentence presentation of such texts (Memory for Individuals Task) is determined by the number of properties known for the individual referred to in the current sentence, and is not significantly affected by the number of known properties of the other individual. Reading times increase as the number of known properties of the referenced individual increase. This phenomenon of rising reading times is referred to as the 'Semantic Ordinal

Effect'. Further, this effect is a reasonably general one since it is also evident for texts presented in different ordering of attributes, such as the following one in Predicate by Predicate mode (as opposed to the Individual by Individual mode of the preceding example) where reference switches between pairs of individuals on every sentence:

> There is a chef. There is a vet. The chef is sane. The vet is mad.
> The chef is Swiss. The vet is Swiss. The chef is old. The vet is young.

Since the Semantic Ordinal Effect occurs for texts presented in both modes, it is highly unlikely that all the increase in reading times is due to rehearsal processes, which would require more time since the number of syllables would rise in tandem with the number of properties (Baddeley, Thomson and Buchanan, 1975). Instead SSL argue that the Semantic Ordinal Effect can be accounted for by other memory processes such as those associated with loads due to the increase in complexity resulting from having to integrate an increasing number of properties. This assumes that incoming information is not maintained in a superficial form till the eighth sentence, and then integrated into a semantic representation, but progressively assimilated in an increasingly elaborate representation organised around individuals. This process also involves a regular review of the known properties of the currently referenced individual. The bindings between attributes are refreshed and updated, with fresher associations being constructed as the reader learns about more properties of an individual.

SSL present a regression model (described in detail in Chapter 2) which shows how increases in processing loads due to an increase in associations account for a large proportion of the observed Semantic Ordinal Effect. The sorts of construction processes that are postulated reflect the processing loads of the number of possible links between property attributes that can be encoded. The model shows how a large proportion the processing can be accounted for in terms of construction of redundant information such as matching status of property attributes, that is, higher level semantic information about whether individuals' attributes on a particular property dimension are the same (matched) or different (mismatched).

Another regression model based on recall error data tends to support findings based on reading time data and shows a number of things about the nature of representation of solutions to the binding problem. It reveals, first, the extent and the sort of redundant information encoded in the representation, second, how the representation is fragmented and distributed, and third, those parts of the representation structures that are dependent on each other and those that are not. Contrary to what the simplicity of the stimuli texts might suggest, subjects' representations contain far more structure than a simple representation of eight properties. In learning the material they utilise a lot of relevant general knowledge. This is done with relative efficiency since despite overlapping attributes the results show no significant signs of proactive or retroactive interference, and the overall frequency of recall errors was much lower than expected. Hence, redundant information such as matching status and general knowledge is used to solve the binding problem.

More specifically, descriptive analysis of recall error frequency data shows how (higher level semantic) redundant information plays a role in subjects' representation strategies which determines whether some of the representation structure share a common fate in memory or remain independent of each other. This suggests that representation are not built up in the precise order of incoming information as semantic networks theories predict (Anderson 1976, 1983). Recall error patterns were also analysed in terms of the representation of features. For example, one possible feature would be the "profession and nationality" of an individual which can take particular lexical values such as "chef" and "Swiss" or "vet" and "Welsh". This approach enables the investigation of the structure of representations independent of the particular lexical items used to describe individuals. Memory is conceived of having a set of these sorts of feature, and the aim is to develop a model of such a set of features which would predict the observed pattern of recall errors. Though regarded as denoting independent fragments of representations, these features are logically interrelated. SSL present an integrated model of recall performance which suggests that binding is achieved by the representation of many fragmented and highly redundant structures. While some of these features contain implicit contextual information, others do not even refer to individuals. This aspect of recall error analysis will be described in much greater detail in Chapter 4.

2.2. Implications and limitations of the SSL findings

Next we will briefly evaluate the implications of the above findings and compare them with a selection of alternative descriptions of the possible cognitive processes involved in text comprehension and knowledge representation. The SSL study shows that the referential structure of an Memory of Individuals Task (MIT) text, which simple lists lack, results in a very different memory phenomenon and one that greatly facilitates the study of the binding problem in human memory. In evaluating the significance of SSL findings it should be borne in mind that though a typical MIT text is highly constrained compared to a more natural text, as far as resolution of reference is concerned there is no dissimilarity. Indeed, the SSL study shows that a high degree of constraint is necessary if we are to investigate as complex a phenomenon as the binding problem in any detail. Alternative theories based on less constrained texts often fall back on primitive representational elements to solve the binding problem (eg, Johnson-Laird 1983; Rumelhart, Lindsay and Norman 1972; Schank and Abelson 1977). In particular, semantic network representation theories of Anderson and Bower (1973) and Anderson (1983) address the binding problem in a limited manner since the links postulated are content independent structures which the SSL findings show is not the case.

They further show that unlike the wholistic (complete) and localised network representation postulated by Anderson, their model of representation based on recall data suggest a more distributed representation. This findings (reported in greater detail in Stenning and Levy, 1988; Levy 1989; Stenning and Oaksford, 1989) concur with those reported by Jones (1976) who shows that cued recall is better predicted if it is assumed that representation consists of independent fragments of knowledge. The SSL model of representation strongly suggests that the distinction between representation of declarative and procedural knowledge is not necessary to explain how links between property attributes are encoded and remembered or retrieved. Nor it would appear is there any need for an interpretor (or a processor) for combining these two sources of knowledge as required by some theories of knowledge representation which hold sway in the field of Artificial Intelligence (eg, Anderson's ACT). Instead resolution of reference is determined by semantic structures which are embedded in a distributed representation. These structures display complex properties that readers have been observed to utilise during retrieval. The complexity of the representation structures facilitates, and therefore constrains, the set of inferences during recall. Finally, the model predicts no separate mechanism for retrieval because the distributed representations of content also incorporate information about higher level semantic structures which aid subsequent recall. To summarise, content dependent structures, together with a large degree of distributed redundancy determined by higher level semantics such as relational informations of texts has been shown to play a major role in human solutions to the binding problem. In light of these findings, it would seem that systems other than the ones developed to meet the constraints of von Neumann machines[2] are feasible and can provide better approaches to the development of cognitive models of knowledge representation in human memory.

To recap, the SSL study (and a number of other related studies) suggests that comprehension is not simply a matter of retention of incoming information but an active process of construction and organisation of semantic structures in representations determined, amongst other things, by the resolution of reference. The solution to the binding problem is non-trivially dependent on construction processes which determine the nature of the encoded representation structure. Hence we assume that the binding problem can only be fully explored by considering data from more than one source as described above. In

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[2] Backus (1978) considers the related problem of programming constraints imposed by von Nuemann architecture/machines.

the studies reported here, both reading time and recall error data is used to constrain models of construction processes and representation structures. A large amount of effort is devoted to gain a better understanding of the role of construction processes during text comprehension. They provide important clues about the organisation of the semantic structures in representations. It follows that our studies cut across the conventional divisions between short term or working memory and long term memory, and this is just as it should be since any theory of human memory's solution to the binding problem needs to explain how the information is taken into working memory, how an enduring representation which preserves the truth value (literal meaning) of the text is constructed, and, how it is subsequently retrieved. We do not expect to be able to formulate complete explanations for all three aspects of text comprehension but addressing the binding problem in parallel with observing working memory processes involved in the construction of long term representations provides some novel insights. For example, our methodological approach enables us to observe the role of rehearsal during text comprehension and serves to increase our understanding of the 'Articulatory Rehearsal Loop' (ARL), while the results of the second experiment highlights the effect of phonemic and/or semantic similarity on construction processes and their intrusive effect on the representations of individuals.

One of the tasks of the studies reported here was to explore further the role of such redundant information in solutions to the binding problem. The findings of SSL make some significant claims about the processes and structures involved in text comprehension in MIT. However, these findings are based on texts which were presented in highly predictable modes. Subjects report the strategy of encoding the matching status of property dimensions of individuals' attributes. This aspect of texts is also referred to as *matchtype information* or *matchtype structure*, and, it can be regarded as redundant information which is an emergent property of texts in MIT, as is obvious from the examples texts given above. Regression modelling of reading time confirms that this strategy is consistent across subjects. Though, matchtype information is an artifact of MIT texts, as SSL clearly show, taking account of matchtype information enables us to gain some invaluable insights in our understanding of the role of higher level semantics, which to an extent is independent of representations of solutions to the binding problem.

It can be argued that the reading time and recall error results, and the models of construction processes and representation structures based on them, reported in SSL are largely reflected by the highly predictable nature of the stimuli texts. In both text modes (that is, I x I and P x P) subjects could predict the order of all sentences after the second sentence. Little reflection will reveal that the text modes greatly facilitate subjects' strategy of encoding redundant matchtype information. Given the central role that it plays in supporting SSL's respective models of construction processes and representation of the structures, which in turn provides the basis for accounts of certain aspects of working memory processes and long term representations, it is important to check whether these results are not entirely due to the predictable nature of stimuli texts. Both experiments reported in this thesis are motivated on these grounds; they are designed to explore the extent to which the processes and structures postulated by SSL are generalisable to texts with fewer predictable qualities.

Our intention is to investigate the nature of changes in th construction processes and represented structures when the MIT texts are rendered less predictable. In both studies texts are changed in two different ways. In the first one (reported in Chapters 2, 3 and 4), we render the referential order unpredictable so that a subject would be unable to rely on being able to predict the order in which sentences refer to individuals. In the second experiment (reported in Chapters 5 and 6, which is partly motivated by the results of the first one) we investigate the effect of differences between the order of property dimensions in which each individual is described. Results of both studies contribute to our understanding of memory processes in text comprehension.

Findings of the first one include the effect of referential unpredictability on reference resolution and the role of rehearsal in working memory during text processing in the MIT paradigm, and also the development of representation models throw some light on interference during recall. As we reported above the SSL model based on recall errors showed that some predicted representational features contained implicit contextual information and others did not even refer to individuals. We will present a model based on recall performance which does not appeal to features containing contextual information about individuals. Such an approach will provide a more general model of the sorts of logically interrelated fragments represented in order to solve the binding problem. It will further increase our understanding of the complexity of inferences necessary for efficient retrieval. The second experiment enables us to explore the effect of phonemic and lexical similarity on construction processes, and models based on recall error data provide an interesting insight into the effect of order of attribute presentation on the relationship between the literal meaning and representation structures of solutions to the binding problem. A more detailed account of the motivations for each study appears in the appropriate sections in Chapters 2 and 5.

3. Memory for Individuals Task (MIT)

In order to investigate human memory solutions to the binding problem, the MIT is used in both experimental studies reported here. In this section, the MIT is described briefly in order to draw attention to its pertinence to our research goals in terms of its most salient features, and, the kinds of data it provides for further analysis designed to increase our understanding of text processing. Further details of the task appear in Chapter 2.

The MIT involves progressive presentation of information describing individuals (usually two, as in preceding example texts) who may share several properties (usually four). These property dimensions are, shape, colour, texture and size for objects, and, profession, nationality, temperament and stature for people. Pairs of individuals are generated by random selection of one property attribute from each of the four dimensions. For ease of reference the first example of an MIT text given above is repeated here:

There is a chef. The chef is sane. The chef is Swiss. The chef is old.

There is a vet. The vet is mad. The vet is Swiss. The vet is young.

From this example it is evident that all selected items make coherent descriptions of individuals, and subjects have to distinguish between a large number of possible combinations. Following the presentation of one pair of individuals described on four property attribute dimensions (one complete text) a subject faced with a recall menu of eight vocabulary items can make 256 (2^8, assuming that ordering is fixed, otherwise it is 2^8 x 8!) possible responses though, given that the introducing property is repeated in all subsequent sentences this figure is more likely to be 62 (2^6 - 2 degrees of freedom). Given this large number of possible combination, construction processes must ensure that bindings between attributes represent the truth values of specific combinations of resolved references. Since the property attributes of individuals can overlap, that is, be the same, the potential for interference increases in memory. However, observed recall performance is highly accurate which reflects the stimuli material's richness in general knowledge.

It is obvious that knowledge representation is a function of both content and form (format), and that an adequate theory would have to give an account for both, their separate and combined roles in a solution to the binding problem. It should be made clear that we are particularly interested in those semantic structures which reflect the *text/discourse* format rather than sentential *syntax* which remains invariant in all stimuli texts. On the whole, it is the former that is altered in stimuli texts in order to explore a variety of different effects of semantic structures on the representation of bindings between property attributes belonging to individuals. The following are the three main reasons for this constraint to our approach:

(1) The main concern is with the representation of bindings between attributes independent of their lexical semantic values. It is assumed that individual attributes such as "a circle" or "a bishop" have a 'fixed' semantic value in an abstract context-free

sense, and we choose to concentrate on modelling more general aspects of the construction processes of this type of information. This does not undermine the explanatory value of our findings since there is a strong case for looking at memory processes involved in reference resolution, independent of their semantic values, and the general manner in which they are represented to solve the binding problem. This approach is similar to general sentence and discourse parsing models in computational linguistics (eg, Grosz 1985, Koskenniemi 1983).

(2) The precise meaning of content is further affected by readers' general world knowledge and perspective (Dunbar 1988). Nevertheless, it is valid to treat likely cognitive processes of representation construction as invariant or insensitive to content at a basic level. In order to ensure that this is the case and that the effects of general knowledge are kept to a minimum, stimuli sentences are all declarative, that is syntactically invariant, and have highly constrained semantic structures, thus severely limiting the number of possible, valid instantiations of models of texts, and valid inferences dependent on any such instantiations.

(3) Simple texts are also assumed to limit possible interactions between form and content. The increase in complexity due to such interactions have already been mentioned. The following two sentences, both with similar content, as defined above, but different syntactic form (which determines their semantic structures) are a good example of the distinction between these two sorts of information and the complex nature of their interaction (which is given a detailed consideration by Oehrle, 1976):

(1) Mary gave the ball to John.

(2) Mary gave John the ball.

Though ultimately this aspect of knowledge representation will have to be addressed, given the limitation of our understanding of human memory's solution to the binding problem, at this stage it is legitimate to focus on less complex representation structures of higher level information.

These three points highlight the importance of the role of content in memory processes and knowledge representation. Current research in this area is addressing particular aspects of this issue, including differences in rehearsal strategies of particular combinations of attributes (Stenning, Patel, Levy, Nelson and Gemmell, forthcoming) and effects of stereotypical descriptions of individuals on representation strategies. These studies reveal the complexity of interactions between form and content, which in studies reported here is kept to the minimum with the use of highly constrained texts that fall into an intermediate stage between referentially structure-free lists which are free of the binding problem, and, more naturalistic texts, comprehension of which is dependent on highly complex inference making mechanisms which obscures the role and contribution of higher level semantic information to the solution of the binding problem. Stimuli texts employed here are constrained to limit inference making to little more than reference resolution. Content is kept very simple. All of which facilitates development of models of construction processes and long term representation structures with reasonable predictive powers. These advantages of the MIT are fully exploited in the research reported here (and elsewhere including Stenning, Shepherd and Levy, 1988; Stenning and Levy, 1988; Levy, 1989; Stenning, Patel and Levy 1987; Gemmell 1988; Nelson 1988; Stenning 1986; Werner 1985), which shows how construction processes and representation structures deployed in solutions to the binding problem are affected by changes in non-lexical aspects of stimuli texts. Further, our awareness of the role of content ensures that the models are constrained by the requirement that they are compatible with content dependent solution to the binding problem.

The MIT enables us to model comprehension processes determined by reference resolution, and, give a concise analysis of the representation of semantic structures. Because individuals are described incrementally, and their description can be intertwined or alternated it has the potential of providing insights into processes associated with a particular individual during comprehension as well as the structure encoded in representations. It provides an ideal opportunity to investigate the effect of partial representations, that is, the effect of what is already known about an individual (given information), on how subsequent new information is encoded or assimilated. It is intuitively plausible that what a reader comprehends about a part of a discourse text would affect how she comprehends the rest of it. Not only do our results tend to confirm this, but we can model this effect in detail, and in one notable case, relate the findings to rehearsal strategies sensitive to word syllabic length in working memory. Similarly the MIT provided a basis for further investigation into the effect of different sentential ordering on construction processes; we show how phonemic similarity affects construction processes involved in reference resolution, and how this highlights the relationship between the semantic value of attributes and the semantic structure of representations. There is strong evidence to suggest that the (literal) meaning of a text (as crudely defined above) and the representation of text are not homomorphic and that the notion of compositionality of meaning at a literal level does not hold for text (as opposed to sentences or propositions).

3.1. Method of analysis of Memory for Individual Task data

This approach to analyses of reading time and recall error data is motivated on the grounds that we are interested in developing models of construction processes and representation structures involved in text comprehension. Each type of datum affords a different perspective on the nature of human text processing as discussed at the beginning of this Chapter. The MIT provides a rich source of data that enables us to construct models with internal structure as will become evident during the course of the rest of this thesis. As explained in the previous section the resulting memory is well integrated and durable, for which, Artificial Intelligence approach to modelling such as Newell's (1973) is of limited value. This is because conventional computers can perform episodic memory tasks with great ease and binding of properties can be achieved with simple primitive links. Even slightly less trivial semantic structures such as the symbolic links postulated in Discourse Representation Theory (Kamp 1979, 1989) fail to reflect the observed complexities (and weaknesses or fragility) of text comprehension in human memory.

Instead, we chose a more data-driven statistical modelling approach through multiple regression analysis (Kieras 1981, 1984). This involves simultaneous consideration of several sources of data about mental structures and processes during text comprehension. Regression analysis enables the study of independent effects of various factors, and provides a good way of comparing their predicted effects with the observed data through residual analysis. The latter also gives us a measure of the extent to which a regression model accounts for the phenomena, be it either construction processes or relational semantic structures. By separate analyses and modelling of both reading time and recall error data this method constrains the accounts of processes in working memory and long term memory representations postulated to give a non-trivial account of the strategies utilised by humans to solve the binding problem.

Though the models are based on language-behaviour, their formal rigour and emphasis on particular aspects of higher level semantics, enables us view them as models of a more abstract language-system (Lyons 1977). While the investigation of text comprehension benefits from our methodological approach, it is unlikely that separate models based on different perspective can provide a complete picture of text comprehension in human memory. This is because simultaneous consideration of all aspects of comprehension would increase the complexity due to various interaction between variables that is beyond the diagnostic power of analytical tools, and beyond the limited and fragmented understanding of any general principles governing construction processes of representations and the role of general knowledge. A satisfactory but partial resolution to this dilemma is captured by the notion of compatibility between models of construction processes and representation structures.

This methodology is exploratory and the findings presented here should be regarded in part as further evidence in support of this approach. Indeed, both experimental designs were partly motivated by that criterion. Further details on the method of analysis will be described in appropriate sections in all Chapters - Chapters 2 and 4 in particular, where the reading time and recall error analyses of the first experimental study are presented.

Chapter 2

1. Introduction

In the following three chapters we describe and discuss the findings of the first experimental study. The experiment was designed to further investigate the nature of working memory processes and long term memory structures involved during text comprehension. The primary reason for carrying out this study was to extend the SSL account of cognitive processes involved in the solution of the binding problem in the MIT. In this design certain aspects of the MIT stimuli texts are altered to investigate the extent to which the SSL findings are generalisable. The order of switches between referents was altered, as was the dimension order in which individuals were described and the order in which individuals are recalled.

It is important to stress that the MIT is a highly exploratory methodological tool designed to study cognitive processes of memory associated with the representation of solutions to the binding problem. It provides a rich source of data which have so far yielded some very interesting findings about memory processes and knowledge representation. This success has depended on novel applications of existing analytical tools, and the development of new methods of classification and analysis of data. This aspect of the research will become more clear over the next three Chapters. Due to the exploratory nature of the methodology, neither experiment reported here can be regarded as motivated by the simple aim of confirming or rejecting findings reported by SSL. More appropriately they are attempts at extending our understanding and gaining insights into various aspects of construction processes and representation structures involved in text comprehension.

This chapter begins with a brief description of the assumed relationship between observed reading times and underlying cognitive processes. This will be followed by a description of the SSL findings which gives rise to the issue of the likely effects of referential discontinuity and predicate ordering on the Semantic Ordinal Effect. Further, the nature and extent of information available for reference resolution, the effect of unpredictable switches in reference on cognitive loads, and, the role of rehearsal in working memory are explored. Following a description of the use of multiple regression analysis for modelling reading times, we present a model of construction processes during text comprehension.

A model of the effect of syllabic length on rehearsal is given in Chapter 3. Chapter 4 contains the results of recall error analysis.

1.1. Reading time and cognitive processes of comprehension

In this chapter we describe the first experiment, and report the reading time results. The MIT is used to collect reading time data for each sentence in a text. Variation in sentence reading times are analysed to give an account of the cognitive loads of processes in working memory. The regression analysis method is described, and used to support the assumption that reading times primarily reflect the incremental semantic interpretation of individuals' descriptions. The results replicate the findings of Stenning (1986) and SSL (1988), and extend our understanding of construction processes associated with text comprehension.

There are numerous studies which have used reading times as a measure of cognitive processing load. These include studies by Sanford and Garrod (1981) and Sanford (1985). However, their work differs from ours in that they are concerned with the study of how general knowledge is utilised in discourse understanding which, for reasons given in Chapter 1, is not of main concern here. Kieras (1981, 1984) has used a self-paced reading task to study the effect of text coherence, as determined by the ratio of *given* referents to *new* referents (Haviland and Clark 1974), on reading times. Text coherence was manipulated by changes in presentation order which affected the ease with which sentences are integrated with existing, partial, representations. Multiple regression was used to distinguish the relative contributions of representational processing to reading times. Though this is very similar to the methodology used here, Kieras' is concerned with more complex aspects of knowledge integration, whereas these studies are confined to the much simpler and basic domain of reference resolution and representation structures of bound attributes.

2. SSL experimental study

In this section we describe the SSL study in some detail in order to motivate the present study. SSL show that self-paced reading time is a sensitive measure of the processes involved in imposing a semantic interpretation and solving the binding problem in the MIT. Reading time increases as the amount learnt about the referenced individual increases; the Semantic Ordinal Effect. This pattern of rising curve is almost unaffected by known properties of the non-referenced individual. The Semantic Ordinal Effect is observed for texts in more than one mode. This shows that apart from lexical items, such as, "square" or "red", a reader also represents the referential structure of individuals by recruiting associations between attributes of an individual.

SSL model predicts that subjects' representations includes a lot of redundancy. For example, readers explicitly represent that the "square" is "red" and that the "circle" is "green", *and* that both are mismatched on the colour dimension. Sentence reading times are, a function of the number of known properties of the currently referenced individual, and whether the attributes of a property dimension (eg., colour, size, etc) match or mismatch. They interpret the Semantic Ordinal Effect as being due to the increasing time taken up by recruiting associations corresponding to the features of the representations constructed, as the number of properties known of an individual increases. The increase could either be because more associations between properties must be recruited, or because the time to recruit associations fulfilling the greater restrictions imposed by more properties increases.

In the SSL study texts are presented in two modes: Individual by Individual (I x I) and Predicate by Predicate (P x P), examples of which are given in Chapter 1. Note that what a reader knows about the non-referenced individual varies according to the mode in which a text is presented. For instance, when the second individual is introduced, in the I x I mode a reader already knows about four properties of the first individual, while in the P x P mode she knows of one property of the first individual. The Semantic Ordinal Effect is observed for texts in both modes, which suggested that the incremental rise in reading time is largely a function of what a reader knows about the currently referenced individual, and, that knowledge about the other individual in the background has little or no effect on reading times.

SSL present a regression model which shows that the Semantic Ordinal Effect reflects the contribution of processing loads determined by various sorts of possible associations that can be constructed in a representation. If two individuals, say, a chef and a vet, were both tall, happy and Swiss then the structural representation need simply encode the fact that both individuals have matched properties on three dimensions, that is, stature, temperament and nationality. But if the chef is tall, and the vet, short, then a reader has to represent more associations which increase the complexity of the represented structure. The highly constrained nature of the MIT texts facilitate such detailed predictions about the effect of higher level semantic structures on reading times.

As pointed out in Chapter 1, the SSL study used relatively simple text modes in which the order of predicates of each individual is predictable. This raises the obvious question about the extent of the dependency of the construction of associations on predictable referential sequence. In order to address this question, texts in this study are presented in modes which renders the order of individuals' attributes unpredictable by introducing referential discontinuity between sentences. The results show that unpredictable switches of reference, on the whole do not disrupt processing; the Semantic Ordinal Effect is replicated, and the representation of a solution to the binding problem is not significantly affected by referentially discontinuous texts. This study further develops techniques for the analysis of processes of semantic interpretation and the construction of representations. Further insight into the importance of temporal ordering phenomena both in working memory and in longer term representations can be gained by teasing apart several concepts of ordering in this task.

3. Resolution of reference in working memory

In this section we consider more general issues about the effects of referential switches on reading times and the underlying cognitive processes. In the present study readers are forced to switch unpredictably between processing of individuals. In SSL predictable switches between referents introduced a great degree of superficial information based on the order of introduction of individuals, that is whether an individual is the first or the second one being described in the text, also referred to as 'direct information'. Subjects rely on this information to organise the constructed representation, and the error frequency models (which are described in greater detail in Chapter 4) reveal how it is used to organise the semantic structures in representations of individuals. By introducing a degree of irregularity in switches between referenced individuals, we can observe how the representation strategy changes when the implicit information is not so readily available. This should show us whether irregular reference switches disrupt processing more than regular ones, and if so, account for the difference in disruption. Here we show how irregularity increases processing loads depending on the number of properties known about the individual to which reference is switched. In Chapter 4 we show how irregularity results in less implicit information being encoded, and present models of representations based on recall error frequencies that do not appeal to direct information.

3.1. Role of partial representations in reference resolution

Most psychologically interesting studies of anaphoric resolutions make the distinction between antecedents and partial knowledge that is immediately available, and that which is less accessible for resolving anaphors (eg, Sanford and Garrod, 1981; Grosz, Joshi and Weinstein, 1983; Sidner 1979; McKoon and Ratcliff 1980; Marslen-Wilson, Levy and Tyler 1981). The former is generally referred to as being in focus - in using this term we make no theoretical claims. These studies indicate that the ease of anaphora resolution is determined by the likely referents in focus. However, the methods of these studies are unable to identify whether what is in focus is simply pointers to individuals (referents) which otherwise remain out of focus, or if the representations of individuals are brought into focus then how much of the total representation of these individuals is present and in what form. The introduction of unpredictable referential switches, and analysing differences in reading times of sentences where referential shifts occur provides us one way of addressing this issue. Our findings give an indication of the amount of information that is brought into focus and how it might be represented.

3.2. The role of rehearsal in working memory

Working memory studies (Baddeley, 1986) have shown that several storage systems are available for working memory. One such system, the articulatory rehearsal loop and its counterpart acoustic/articulatory store (ARL/AAS system) is of particular relevance in interpreting the Semantic Ordinal Effect. SSL show that the Semantic Ordinal Effect cannot be entirely accounted for by the loads imposed by the rehearsal process of increasing long list of individual attributes. However, rehearsal and the role of the ARL/AAS is not therefore totally discounted; during the MIT some subjects had been observed to spontaneously rehearse aloud and others it is assumed do so internally to varying degrees. The effect of unpredictable referential shifts reading times further facilitates the investigation of the role of ARL/AAS in the construction processes of representation of solutions to the binding problems. This is given further consideration in Chapter 3, where we present a model of the effect of the number of syllables on reading times which enhances our understanding of the rehearsal processes involved, and the role of ARL/AAS system in text comprehension.

3.3. Effects of referential discontinuity on working memory processes

Spreading activation theories (eg, Anderson 1983) of search through semantic networks are another approach to the study of working memory which make claims about the effects of referential discontinuity. According to Anderson, repeated reference to an individual initiates activation at its node in the network which spreads outwards and dissipates. Switching reference to an individual represented by another node, or the introduction of a new individual requiring the construction of a new node, will temporarily depress the achieved level of activation. On switching back to an established node, it is predicted that the time taken to reach a given activation level will be an increasing function of the number of arcs emanating from the node (otherwise referred to as the 'fan' of the node). This is because activation will disperse more rapidly from a node with many outgoing arcs. Anderson's theory is supported by the evidence from search tasks, rather than from construction tasks like self-paced reading, but the theoretical interpretation clearly has implications for the MIT.

SSL's results, however, raise questions about this interpretation of the process load of reference switching. As already mentioned their study included two organisations of texts, I x I and P x P mode. The observed Semantic Ordinal Effect for texts in each mode are very similar and regression modelling of reading times show that the effects of these different text modes are very slight and local, and certainly not as large as Anderson's theory would have predicted. Reading times are primarily determined by the semantic structure, and are little affected by variations in ordering which, with regard to this structure, remain invariant across texts in different modes. However, texts in both modes were referentially predictable in that after the second sentence, the individual to which all subsequent sentences referred to is always predictable. Perhaps this would explain the lack of congruity between predictions based on Anderson's theory and the observed reading times reported by SSL. Predictability in reference switches may allow the activation process to start earlier, and it could have proceeded in parallel with other time-limited processes in working memory. Texts with unpredictable referential switches should enable us to observe whether the cost of switching is dependent on predictability. If referential switching costs no time-limited resources when it is predictable, but does so when it is unpredictable, then it will influence our theoretical interpretations of the processes involved in reference shift. Alternatively, one might question whether the simple mechanical spread of activation is an adequate theoretical vehicle for explaining what can be highly structured processes controlled by executive mechanisms. Whatever explanations can be offered, it is important to establish whether the processes involved in referential switching are affected by the predictability of its occurrence.

A final source of observations and explanations of the effects of discontinuities of reference is the literature on verbal inference. Ehrlich and Johnson-Laird (1982) and Stenning (1986), among others (see McGonigle and Chalmers 1986 for a review) have used self-paced reading time to investigate subjects' construction of representations while reading inferential texts. Ehrlich and Johnson-Laird, report that referential discontinuity which introduces new individuals results in an increase in subjects' reading times. On reviewing some of the work on premise contour McGonigle and Chalmers (1986) conclude that though the evidence in not conclusive, introducing new referents, and switching reference between individuals should generally result in increases in higher reading times. This is interpreted as a consequence of indeterminacy due to referential discontinuity which temporarily increases memory load in working memory.

While reading times in the present study do increase when reference is switched, it cannot be explained as a consequence of unresolved information since the referent of each predicate is unambiguously stated in all sentences of texts. Further, the results show that subjects do not slow down when the second individual is introduced. These differences are probably due to the fact that there can be several sorts of indeterminacy possible in texts, and that the ones occurring in the present task are not similar to the ones in previous studies. In Stenning, Patel and Levy (1987)at least five[3] sorts of indeterminacy in texts are

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[3] These categories are not intended to be exclusive: more than one type may occur at the same point in a text.

identified. These are:

(1) In a text where all referents are already known, it may be indeterminate which referent will be mentioned next.

(2) It may be known that new referents will be introduced but not when they will be introduced.

(3) It may be known that new referents will be introduced, but not known what sort of thing they are.

(4) It may be known what references will be made, but not what relations (for example, what spatial relations or ordering relations) they bear to other known referents.

(5) There may be true referential indeterminacy, in the sense that it may not be possible to tell whether two referring terms in the text refer to the same or different referents.

Type 5 indeterminacy has not received much attention. It has been investigated by Stenning 1986 but does not occur in the present task and will not be further discussed here.

Type 4 indeterminacy is characteristic of certain inferential tasks. In an N-term series problem which is not stepwise determinate of a full ordering of its referents (eg, A > C, B > C, A > B), all *references* are fully determinate at all times, but the *relations* between some subsets of referents are indeterminate. This is the sort of indeterminacy which chiefly concerns Johnson-Laird and Ehrlich, but their texts also contain indeterminacies of types 1, 2 and 3. If a representation requires these relations to be specified, construction must either await determination or proceed with the expectation of possible backtracking for correction. This distinction between these two strategies of representation is discussed by Mitchell (1984) in terms of construction being under either *direct* or *buffer* control. SSL results show that for the MIT construction of a representation does not necessitate backtracking (or buffer control). This is confirmed by findings from another relevant study by Mani & Johnson-Laird (1982). They show that only texts with indeterminate information of types other than 1 and 2 seem to require extra processing associated with holding unresolved (verbatim) information is some sort of buffer storage.

4. Unpredicatable referential discontinuity experiment

Stenning (1986) and SSL employ texts in which only type 2 indeterminacy occurs, whereas the present experiment is designed to study indeterminacy of types 1 and 2 systematically. This enables us to investigate the nature of the processing loads underlying the pattern of increases in reading times due to unpredictable referential shifts. In earlier studies, small sets of individuals (either objects or people) are attributed between two and four properties drawn from shape, texture, colour and size dimensions for objects and profession, nationality, stature and temperament dimensions for people. The property attribute dimensions are presented in either I x I (Individual by Individual) or P x P (Predicate by Predicate) modes. For texts in both modes, at any stage after the second sentence, subjects could predict both, the referenced individual of each subsequent sentence, and, the property dimension of individuals' attributes. Note that even when a sentence introduces a previously unmentioned individual, the subject knows a great deal about the form this introduction will take. For example, if a pair of individuals are being described in I x I mode on four dimensions, at the fourth sentence the subject knows that the next (fifth) sentence will introduce the other individual, and that it will describe the profession attribute contrasting with that of the first individual.

This study was primarily designed to check if the Semantic Ordinal Effect is an artifact of predictable switches between referents. The aim was to study the effects of making the referents of the next sentence as unpredictable as possible, whilst continuing to study texts describing the same overall semantic structures (pairs of individuals with four properties each). Texts in this study were, therefore, presented in seven different modes. The first sentence is, by definition, about the first individual. Once four properties have been described for one individual, the reference of future sentences to the other individual is completely determined. So it is impossible to make reference completely unpredictable, but it is possible to make it unpredictable at most sentence positions in the texts. The results show that the Semantic Ordinal Effect is independent of the order in which individuals' attributes are presented, and, that self-paced reading times are determined by the interpretation of the currently referenced individual; the more a reader knows about an individual the longer it takes to encode new information about that individual, and this is not affected by what is known about the other individual.

Further restrictions were operating in these earlier studies in the form of constraints on the ordering of property dimensions. A fixed order was employed; texts describing individuals always introduced their profession first, followed by nationality, temperament and stature attributions in that order. A subsidiary goal of this study was to investigate whether different reading time phenomena would be observed with texts that used different orders of attribution of the property dimensions. This order of dimension in texts will be referred to as the 'format' of an MIT text. Without observing reading times of texts presented with other orders, it is impossible to say whether the Semantic Ordinal Effect is an effect of the *number* of properties known of an individual independent of one particular format.

There are distinct natural orderings of predicates within texts and within phrases. Within texts, we would not normally introduce a character in terms of their temperament only later to describe their profession or nationality. On the other hand, within the noun phrase, there is a fairly fixed partial ordering of adjectives before the head noun. In a noun phrase, adjectival ordering such as "A tall sad Polish bishop" is, a more normal than "A Polish sad tall Bishop" (Quirk et al, 1985). The textual ordering is related to the noun phrase ordering only in that we normally choose the most nominal predicate to introduce a referent, which can then be followed by other properties predicated in any order suitable for our rhetorical purposes. What, for instance, would be the effect of using the least nominal property to introduce an individual? To see what, if any, quantitative and qualitative processing changes such an ordering might lead to, the four property dimensions (shape, colour, texture and size) were presented in two different formats - these are referred to as *forward* and *backward* formats. Texts in *forward* format introduced with the shape of an individual followed by the description of its colour, texture and size, and texts in *backward* format described an individual in the reverse order, beginning with the size of the individual followed by its texture, colour and shape. Note that the same ordering always applies to both individuals within a particular text format. There is no indeterminacy about which dimension will occur next except at the first sentence. The second study presented in Chapters 5 and 6 is primarily designed to address this issue in a more sophisticated manner and in greater detail.

In this chapter we will describe the design and the procedure of the experiment, and present analysis of reading time data. Reading time effects are compared with the SSL model by building a regression model which includes variables representing switches of reference in various circumstances. The results of this modelling suggest that certain groups of modes are processed slightly differently. The usefulness of the multiple linear regression technique in modelling the contribution of a large number of predictor variables to reading times will be made evident. Review of some of the issues involved in the use of multiple regression techniques and their application to modelling reading time data can be found in Kieras and Just (1984: see articles by Knight, Haberlandt, and, Graesser and Riha), Draper and Smith (1966 and 1981), and Cohen and Cohen (1983).

In Chapter 3 we report analysis of reading times in terms of the effect of rehearsal processes during the construction of representations of structures deployed in the solution of the binding problem. A regression model of the reading time data incorporating variables representing rehearsal processes dependent on syllabic length is presented.

The effect of different processing of modes on the representation of semantic structures is explored by analysing the patterns in recall error data, which is presented in Chapter 4. Investigation of the accuracy with which the temporal recall cues are obeyed in different modes enables us to identify two groups of modes which demand separate analysis. We develop and compare direct models of the error data from the present experiment with the SSL model, and then go on to develop and compare radically indirect models of these error data. These error analyses reveal some representational differences between the groups of modes.

5. Method

5.1. Design

Texts are read by subjects one sentence at a time in a self-paced reading time task. Each text consisted of eight simple declarative sentences describing two individuals in terms of their shape, colour, texture and size. The individual introduced by the first sentence will be termed the first individual (also referred to as 'individual-1'). Each possible sequence of references to the two individuals will be termed a 'mode'. There are 35 possible modes of presentation; Figure 1 shows all the possible text positions in which the first, second, third and fourth predication of an individual can occur, for both the first and second individuals.

Figure 1

Possible temporal position of property dimensions (1-4) of each individual

Sentence:	Individual 1	Individual 2
1	1,	-
2	2,	1
3	2, 3,	1, 2
4	2, 3, 4,	1, 2, 3
5	2, 3, 4,	1, 2, 3, 4
6	2, 3, 4,	2, 3, 4
7	3, 4,	3, 4
8	4,	4

Texts were presented in seven of the thirty five different modes. These seven were chosen so that each predication occurred at each of its possible temporal positions in at least one mode. Table 1 shows the sequence of sentences for each mode; letters identify the individual, and numbers, the property dimensions. Two examples of texts in modes one and four are given at the end of this section (examples of texts in all seven modes are given in the Appendix A). Texts of different modes were presented in random sequence in the experimental session.

Table 1

Text sentence position in each mode

Temporal Position:	1	2	3	4	5	6	7	8
Modes:								
1	(a 1)	(a 2)	(a 3)	(a 4)	(b 1)	(b 2)	(b 3)	(b 4)
2	(a 1)	(a 2)	(a 3)	(b 1)	(a 4)	(b 2)	(b 3)	(b 4)
3	(a 1)	(a 2)	(b 1)	(b 2)	(b 3)	(b 4)	(a 3)	(a 4)
4	(a 1)	(b 1)	(a 2)	(a 3)	(b 2)	(a 4)	(b 3)	(b 4)
5	(a 1)	(b 1)	(b 2)	(a 2)	(a 3)	(b 3)	(a 4)	(b 4)
6	(a 1)	(b 1)	(b 2)	(b 3)	(a 2)	(a 3)	(b 4)	(a 4)
7	(a 1)	(b 1)	(b 2)	(b 3)	(b 4)	(a 2)	(a 3)	(a 4)

Two sequences of property dimensions orders were used. In the *forward* format predicate dimensions appear in the order <shape, colour, texture, size>. This order is the one used by SSL. In *backward* format the order of predicate dimensions is <size, texture, colour, shape>. Both individuals in a text were described in the same format.

For both formats the *introducer* property is always mismatched. Individuals were matched or mismatched on the other three predicates equally often. Thus there are eight different structures of matching, referred to as *matchtypes* or sometimes as, *matchtype structures,* and annotated: +++, ++-, +-+, +--, -++, -+-, --+, and ---, where a '+' denotes a match and a '-' a mismatch, and the three symbols represent the three dimensions' temporal order in the text. (Examples of texts in each matchtype are given in the Appendix

B). Each matchtype occurred 14 times in each subject's stimuli, otherwise it was randomised with regard to mode and format.

The following are two example texts, one in *forward* format and mode 4 and the other is in *backward* format and mode 1. The formers attributes are mismatched on the first, third and fourth dimension and matched on the second (that is, matchtype -++):

Mode 4 (forward) -++	Mode 1 (backward) -+-
There is a cylinder	There is a narrow thing
There is a pyramid	The narrow thing is soft
The cylinder is red	The narrow thing is white
The cylinder is cold	The narrow thing is a block
The pyramid is red	There is a wide thing
The cylinder is thick	The wide thing is hard
The pyramid is hot	The wide thing is white
The pyramid is thin	The wide thing is a beam

Each subject did 8 sessions. One session had 14 texts, two in each mode; one in each format. Matchtype of texts was randomised over the 8 session, each occurring 16 times. The full design consisted of the following factors (and levels):

1) Mode (7 levels)
2) Individual (2 levels)
3) Predicate (4 levels)
4) Format (2 levels)

All factors were within subject factors and were fully crossed.

5.2. Vocabulary

The vocabulary set contains 48 words, twelve each of words denoting shapes, colours, textures and sizes. (The groupings 'texture' and 'size' are rather approximate labels for somewhat miscellaneous groupings of properties). Each cohort contains six pairs of antonymous or contrasted nouns or adjectives as given is Table 2. A pair of individuals is described by attributes chosen from four contrasting pairs, which are in turn chosen, one pair from each cohort of vocabulary. An individual could never be described with both adjectives of one pair. The texts were generated in Franz LISP on a VAX computer. Attributes from each vocabulary cohort were randomly assigned to describe individuals.

Table 2

Vocabulary Set

Cohort 1	Cohort 2	Cohort 3	Cohort 4
circle/square	black/white	old/new	thick/thin
triangle/oval	red/green	hard/soft	deep/shallow
rectangle/ellipse	yellow/blue	rough/smooth	hollow/solid
beam/block	silver/gold	wet/dry	large/small
cylinder/pyramid	bright/dim	hot/cold	long/short
disc/cube	shiny/dull	light/heavy	wide/narrow

5.3. Subjects

There were 10 postgraduate student subjects who were paid four pounds for taking part in the experiment.

5.4. Procedure

Subjects were presented the texts on a BBC model B microcomputer monitor. Each subject read 112 texts over eight sessions. A session contained seven texts in each format, *forward* and *backward*, and one in each mode.

Subjects were provided with written instructions (see Appendix C) which were supplemented with detailed verbal instructions during the trial session. Subjects were instructed to read the texts as quickly as possible, consistent with recalling them accurately. They were allowed to take breaks of any length of time between sessions. The majority completed the sessions in two or three sittings.

Each text was preceded by a *setting* which displayed the paired attributes which might be used to describe the individuals. Below is an example of a setting:

(beam/block) (black/white) (hard/soft) (wide/narrow)

The setting remained visible until the subject pressed the space bar. Pressing removed the current display and presented the next sentence. Times were measured between bar presses in centiseconds. At the end of each text, following a warning message, the subject was required to answer a simple question such as "Was there a large square?" The response to the question was followed by a request to recall the individuals described by the most recent text, using a menu selection system. The subject was cued either to recall the individuals in presented or in reverse order. A menu then appeared offering a choice between the two contrasted properties on each dimension. After recalling one individual by making selections from the menu, the process was repeated for the other individual. After the recall stage, feedback was given in the form of a single sentence description of both individuals presented (eg, "There was a narrow soft white block and a wide hard white beam"). Subjects were provided with no other feedback on the accuracy of their recall of each individual. Subjects pressed the RETURN key to begin the next text presentation.

6. Reading time results

Below we report the results of standard statistical analysis on reading time data. Much of the descriptive data was presented in Patel (1985). All reading time means are given in seconds unless otherwise indicated. The data were subjected to a ANOVA with subjects as the random factor and mode (7 levels), format (2 levels), individual (2 levels) and predicate (4 levels) as fixed factors.

There is a main effect of mode (F (6,48) = 5.94, $p < 0.0002$). See the mode total column in Table 3 for mean reading times each mode. Mode 1 (I x I) had the fastest mean reading time per sentence followed by modes 7, 3, 6, 5, 2 and 4 respectively.

There is a main effect of predicate (F (1,8) = 21.8, $p < 0.0001$). This effect is due to a rise in reading time from predicates one to four (the means were 1.82, 2.03, 2.13 and 2.75 seconds respectively). There is no main effect of individual (F (1,8) = 1.52, $p = 0.25$). This combination of effects - a rise in reading time with predicate position and a lack of difference between individuals - constitutes a replication of the Semantic Ordinal Effect for texts with unpredictable reference.

There is also a main effect of format, (F (1,8) = 20.89, $p < 0.002$). Texts in *forward* format were read significantly faster (mean reading time 2.04 secs.) than those in *backward* format (mean reading time 2.33 secs.). However, there is no significant interaction between format and any other factor. This shows that the Semantic Ordinal Effect is not dependent on a particular predicate ordering in the MIT texts.

The interaction between mode and predicate is significant (F (18,144) = 5.2, $p < 0.0001$), as are the interactions between individual and predicate (F (3,24) = 12.17, $p < 0.0001$), and between mode, individual and predicate factors (F (18,144) = 4.55, $p < 0.0001$). Mean reading times for each individual for all modes are given in Table 3. These two interactions show that although the Semantic Ordinal Effect appears in this data, it is not completely independent of the temporal sequence of predicate attributes of individuals.

Table 3

Mean reading times as a function of individual, predicate and mode

	Individual 1				Individual 2				All
Predicate:	1	2	3	4	1	2	3	4	Predicates
Mode 1	1.95	1.72	1.66	2.71	1.89	1.65	1.58	2.22	1.92
Mode 2	2.02	1.75	1.76	4.08	2.06	2.27	1.92	2.44	2.29
Mode 3	1.96	1.74	2.49	2.41	1.67	2.03	2.29	2.83	2.18
Mode 4	1.74	1.88	2.28	3.67	1.60	2.41	2.58	2.23	2.30
Mode 5	1.81	2.09	2.56	2.74	1.78	2.18	2.39	2.45	2.25
Mode 6	1.85	2.00	2.38	2.63	1.74	2.36	1.99	2.88	2.23
Mode 7	1.81	2.15	1.75	2.52	1.64	2.22	2.14	2.67	2.11
All Modes	1.88	1.90	2.13	2.96	1.77	2.16	2.13	2.53	

7. Development of multiple regression model

The purpose of building a regression model is to arrive at a better articulated description of the functions that relate reading time to various cognitive processes; it allows us to investigate the degree of modularity of processes that take up reading times. We wish to know how reading time is related to the amounts of different types of information being constructed and held in memory. Rather than interpreting directly the complex interactions between mode, predicate and individual observed in the ANOVA's, variables are added to account directly for interactions. Multiple linear regression statistical techniques can be used to provide the best account of the variance in the data. It enables us to select variables that distinguish between the loads imposed by various working memory processes, and, by assigning a coefficient to each variable it provides a more precise account of the relative contribution of component cognitive processes to observed reading times. A detailed study of residuals (the difference between predicted model and observed data) is a very useful way of refining our definitions of independent variables. Of course, because of the ease with which data can be modelled it can be misused; we have avoided generating spurious models which simply fit the data by ensuring that very similar models fit data from completely different experiments. The present study being a good case in point, where we present the SSL model for direct comparision with our model which included extra variables that are strictly motivated to take account of the controlled differences between the two experimental designs. In this study the multiple regression statistical procedure allows us to model the contributions of unpredictable referential switches and format to reading times.

Since the current model is based on the SSL model, that model will be described briefly before we consider the changes that were made in order to model the effect of referential unpredictability and format. The design of the multiple regression model is based on the observed Semantic Ordinal Effect. As readers learn more about an individual they spend longer reading new bits of information about that individual. Reading times are not affected by how much is known about individuals other than the one currently referenced. SSL show that reading times are closely determined functions of what is known about the referenced individual, and that changes in them is sensitive to relations between properties of the pair of individuals. So, if the current sentence attributes a property of the referenced individual which is known to *match* that of the other individual (that is, when both individuals are the same colour, "red", for example), then the current sentence is read more quickly than if it attributes a property that is known to *mismatch* (one being "red" and the other "green") that of the other individual. This makes sense since the information imparted by matched and mismatched dimensions varies. For a matched dimension, subjects only need to represent the fact that both individuals have the same attribute. However, for mismatch attributes subjects need to remember not only two different attributes but it would also be necessary to represent *which* attribute belongs to *which* individual. Reading times are similarly higher for indeterminate properties, that is when the current sentence describes an individual on a property dimension on which the other individual has not at that point been described (for example, when it is known that one individual is ‘red’ but information about the other individual has not yet been presented). In other words, information about the matchtype structure, or the lack of it, affects reading times, and is therefore used by readers to represent solutions to the binding problem. Hence. matchtype information was used to define independent variables to predict reading times, which is factored into several distinguishable parts (which denote cognitive processes) each of which occurs whenever its conditions are fulfilled, and which have the same definitions wherever they occur in the text.

The SSL model, presented in Table 4, accordingly includes variables that represent cumulative loads of these various sorts of attributes in memory. These cumulative loads are MATLOAD, MISLOAD and NEUTLOAD, representing the accumulated number of three sorts of properties - matched, mismatched or unresolved (in terms of matchtype information) attributes - at a given point in the text. The reading time taken up by these accumulating loads are interpreted as being taken up by construction processes, and our goal is to investigate the nature of these processes.

The process of modelling the SSL data revealed locally occurring processes which do not impose recurrent load. A variable, LOCALMIS, associated with such a process of the detection of a mismatch between the two described individuals was shown to contribute to the reading time of the current sentence, but not to subsequent ones about the same individual. This variable provides a good example of the capacity of multiple regression modelling to factor out processes and clarify relationships between variables that would otherwise remain obscure.

Table 4

Summary of regression model predicting reading times from matchtype structure (Stenning, Shepherd and Levy, 1988)

Variable	Coeff.	Standard Error
Intercept	1.09	.066
NEUT1	0.28	.049
NEUT2	0.47	.092
NEUT3	0.73	.092
NEUT4	2.07	.092
MIS1	0.46	.062
MIS2	0.79	.076
MIS3	1.15	.090
MIS4	1.37	.150
MAT1	0.42	.063
MAT2	0.58	.090
LOCALMIS	0.19	.065

The variables MATLOAD, MISLOAD and NEUTLOAD from the SSL model were included in our model. In addition, to account for the effect of referential unpredictability and format three more variables were constructed. There are also likely to be processes which precompute certain information which can be confidently predicted to be present in all texts. A good example of this is fact that subjects know that each text describes two individuals which could be preprocessed. This is a likely explanation for the fall in reading time at sentences which introduce the second individual.

CONTOUR is a binary variable with value 1 if the referent in current sentence was different from the previous sentence's referent. This described the process associated with the detection of a switch in reference. It's value is 0 at sentences where there is no switch. (At initial sentence position CONTOUR had value 0).

FOREGROUND, accounts for processes associated with the foregrounding of partial representation of individuals to which reference is being switched. The pattern of increases in observed reading times indicates that this was partly determined by the known number of properties of the newly referenced individual. It is a variable taking a value between 1 and 3. If CONTOUR's value was 1, then FOREGROUND's value was equal to the number of properties known of the individual to which reference had just been switched, that is after a switch, FOREGROUND is the number of properties known of the individual which has to be 'moved' from background to foreground. This represents the relationship between the amount of processing load of a shift in focus and the number of properties being foregrounded. If CONTOUR's value was 0, then FOREGROUND's value was also 0.

Finally, a binary variable FORMAT was defined to take account of the difference in reading speed for the two formats of text. Since the ANOVA showed that the formats affected reading time but did not interact with any other variable, this binary variable was adequate to describe the effect of format.

Table 5 shows examples of the values of each of the independent variables assigned at each point in texts in mode four (which has mismatched attributes on the first, third and fourth dimension, and one matched attribute on the second dimension), and mode seven (which has mismatched attributes on the first, second and third dimension, and matched attributes on the fourth dimension). Exhaustive tables of values taken by these variables in texts in other modes is given in Appendix D.

Table 5

Two example of values taken by each regression variable

Text	MISLD	MATLD	NEUTLD	CONTOUR	FOREGRD	FORMAT
Mode 4 (forward) +--						
There is a circle	0	0	1	0	0	0
There is a square	1	0	0	1	0	0
The circle is red	1	0	1	1	1	0
The circle is cold	1	0	2	0	0	0
The square is red	2	0	0	1	1	0
The circle is thick	2	0	2	1	3	0
The square is hot	2	1	0	1	2	0
The square is thin	3	1	0	0	0	0
Mode 7 (forward) --+						
There is a triangle	0	0	1	0	0	0
There is an oval	1	0	0	1	0	0
The oval is yellow	1	0	1	0	0	0
The oval is dry	1	0	2	0	0	0
The oval is solid	1	0	3	0	0	0
The triangle is blue	1	1	0	1	1	0
The triangle is wet	2	1	0	0	0	0
The triangle is solid	3	1	0	0	0	0

7.1. Selecting and fitting regression model

A simple regression model predicts reading time coefficients which increase at a constant rate in line with an increase in the respective values of independent variables. But as SSL point out such a model would be too simple since the matching status of properties makes a difference, and, the time taken is not linear with the number of properties. Thus, in order to allow the data to determine the shape of the functions, dummy variables are used to represent each of the variables MISLOAD, MATLOAD, NEUTLOAD and FOREGROUND. (See Draper and Smith, 1981 for a discussion of the use of dummy variables in multiple regression). Briefly, the *n* levels of a pseudo-continuous variable are represented by *n-1* binary variables, each defined so they take the value 1 at their unique level of the parent variable, and otherwise the value 0. The functions defined by the dummy variable is used to constrain theories of what processes underlie the observed reading times. The selection of a best-fitting model was performed by program P9R of the BMDP package, using Mallow's CP statistics (Dixon et al, 1968, 1983). Variables used in the regression model were as follows:

(1) MISLOAD is the number of mismatches on the referenced individual. This factor was expressed as dummy variables MIS1, MIS2, MIS3 and MIS4. Each had a value of 1 if MISLOAD's value corresponded to its number, otherwise its value was 0.

(2) MATLOAD is the number of matches on the referenced individual. This factor was expressed as dummy variables MAT1, MAT2 and MAT3, in the same manner as MISLOAD.

(3) NEUTLOAD is the number of unresolved properties on the referenced individual which cannot be assigned as matched or mismatched with the attributes of the background individual. This factor was expressed as dummy variables NEUT1, NEUT2, NEUT3 and NEUT4, in the same manner as MISLOAD.

(4) CONTOUR is a non-cumulative binary variable which has a value of 1 when a switch in reference occurs.

(5) FOREGROUND is a non-cumulative variable which takes a value at all except the first CONTOUR switch. The factor was expressed as dummy variables FORE1, FORE2 and FORE3. Each had a value of 1 if FOREGROUND's value corresponded to the number of properties of the individual being foregrounded when a switch in reference occurs, otherwise it is 0.

(6) FORMAT is non-cumulative binary variable which has a value of 1 when the referenced individual is presented in *backward* format.

8. Reading time regression model results

The regression procedure selected dummy variables for all levels of all the variables except MATLOAD, for which it selected no dummy variables. Table 6 shows the selected variables, their coefficients and their standard errors. The contribution of each variable to $\mathbf{R}^2$ is significant ($p < 0.01$). Pure error accounts for 87.27% of the total variance. Of the remaining variance, the regression model accounts for 81.4%, leaving 2.37% lack of fit.

Table 6

Summary of regression model predicting reading times from matchtype structure and referential discontinuity

Variable	Coeff.	Standard Error
Intercept	1.25	.067
FORMAT	0.23	.057
NEUT1	0.28	.047
NEUT2	0.38	.054
NEUT3	0.67	.069
NEUT4	1.31	.115
MIS1	0.52	.042
MIS2	0.73	.055
MIS3	0.73	.070
MIS4	0.66	.123
CONTOUR	-0.18	.067
FORE1	0.21	.060
FORE2	0.50	.076
FORE3	0.85	.075

Figure 2 shows the observed and predicted reading times at each sentence position for each matchtype. It indicates the impact of matchtype information on the processing of one individual in terms of the other. Figure 3 shows the observed and predicted reading times at each sentence position in each mode, and for all modes combined. It indicates the relative fit of the general model to reading times observed in each mode, which shows that on the whole the combinations of independent variables selected by the model account for reading time differences due to different referential orders. The graph showing the fit between the general model and data collapsed across modes shows a reasonable overall fit.

Figure 2: Observed and predicted reading times of predicate by matchtype

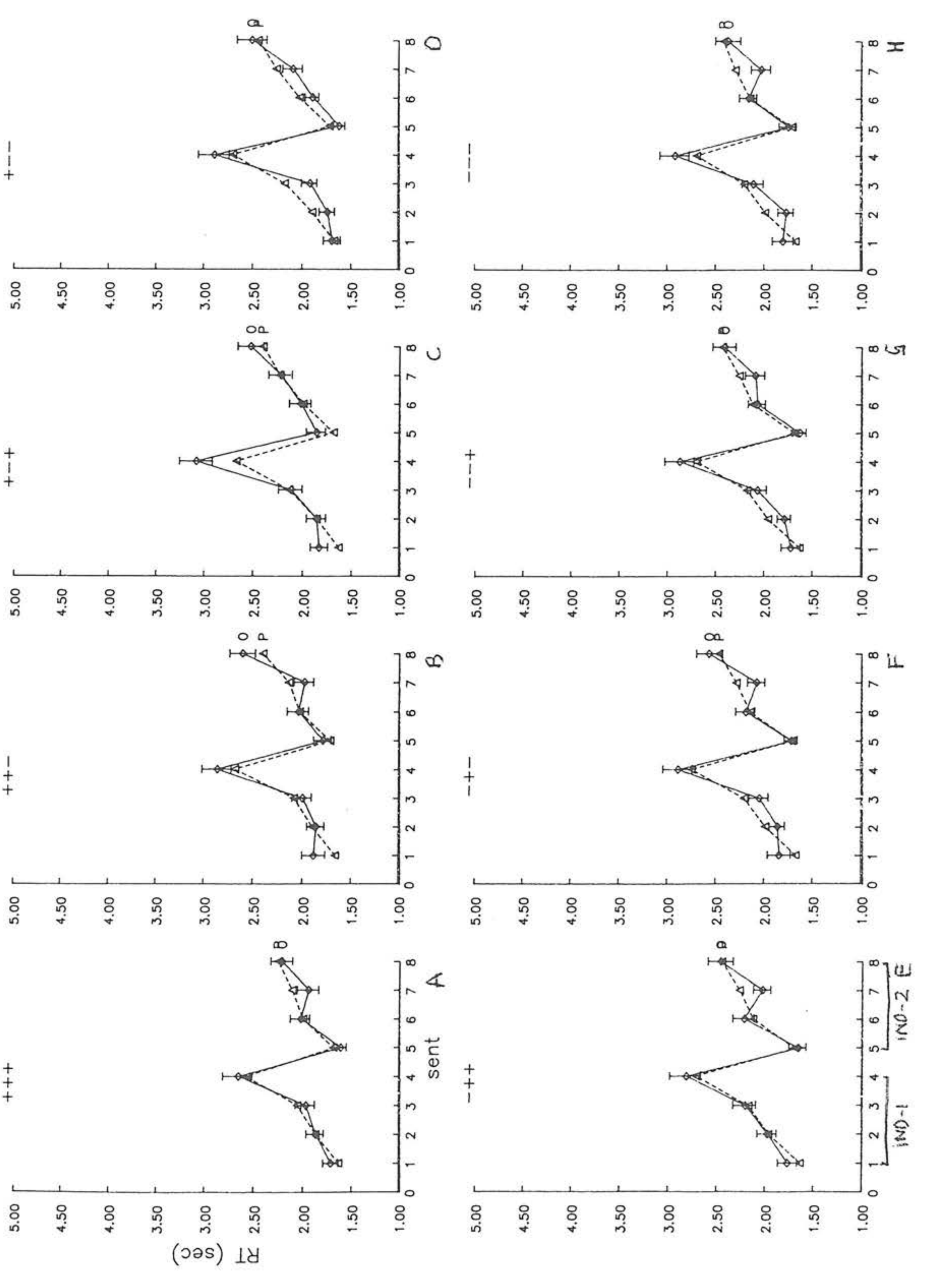
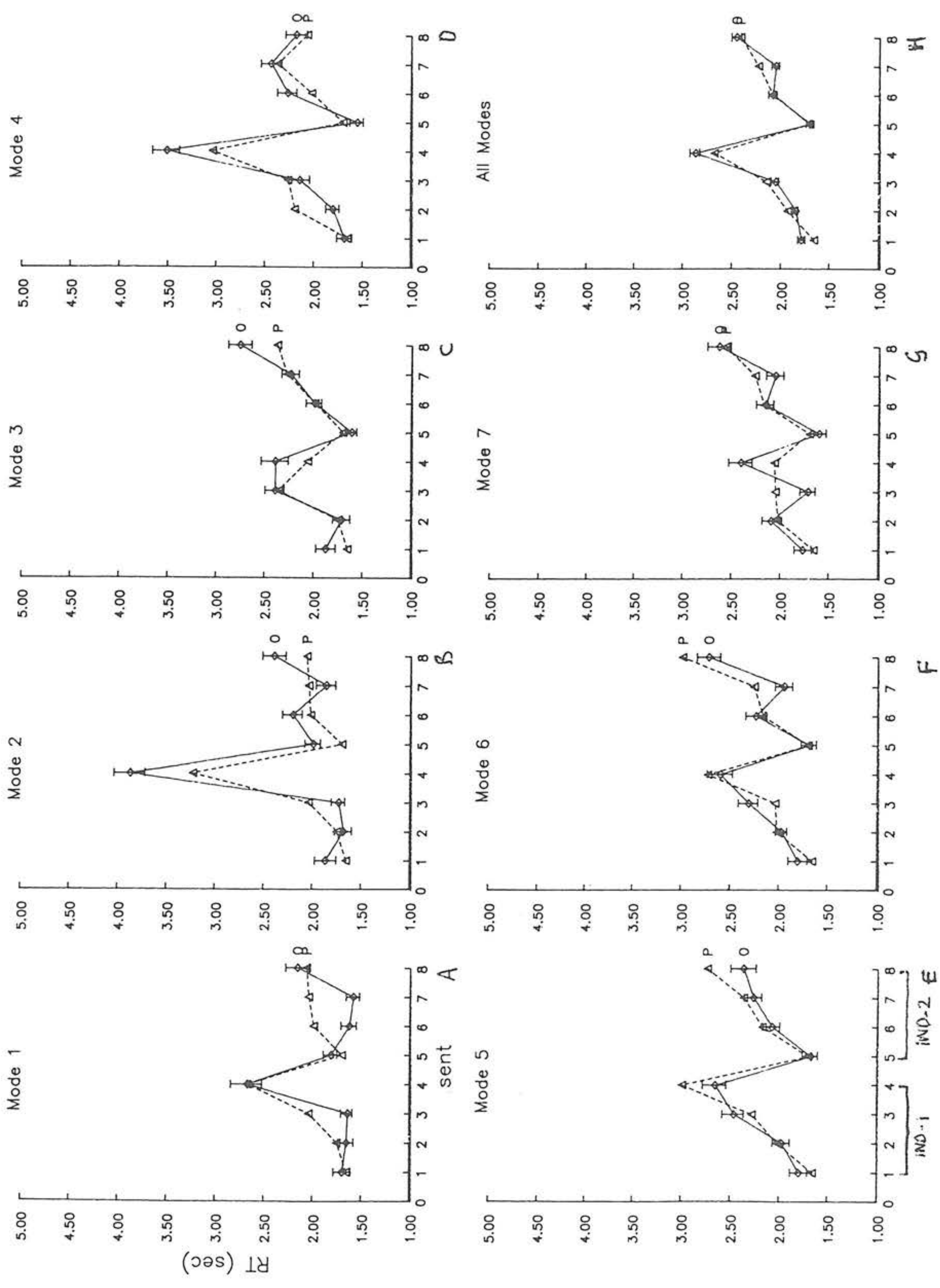


Figure 3: Observed and predicted reading times of predicate by mode



The shape of the NEUTLOAD function which rises by small amounts for the first two levels, followed by large rise between the third and fourth level is similar to the one in the SSL model. The shape of the MISLOAD function in the present data is different from that in the earlier model. The present MISLOAD function is very similar for the first two points, but then levels off and actually declines at MIS4. This difference is combined with the absence of LOCALMIS, and MATLOAD from the new model.

The effects of referential switching are best assessed by considering CONTOUR and FOREGROUND together. The combined contribution of CONTOUR and FOREGROUND gives us five levels for which the model predicts the coefficients, 0, -0.18, 0.03, 0.32, and 0.67 seconds respectively. Continuous reference provides a baseline against which to compare the effects of referential change. This baseline is when both variables have the value of 0. Switching to the introduction of a new referent saves 0.18 seconds reading time. CONTOUR affects the coefficient of first instance of MIS1; it reduces the initial contribution of MIS1 to 0.34 seconds: all subsequent predicted contributions of MIS1 are not affected. This suggests that subjects may be preemptively encoding the fact that the introducer is always mismatched. This probably reflects the determinacy in texts that always describe two individuals.

A switch in reference to individuals with one, two and three previously known properties contributes 0.03, 0.32, 0.67 seconds reading time respectively. The almost linear rise in these values show that the foregrounding process is a function of the number of properties known of the individual to which reference is being switched. Hence, in the texts considered here (which describe two individuals) the extra processing associated with a discontinuity in reference seems to be determined by the number of known properties of the referenced individual.

The contribution of FORMAT to reading times is constant (0.23 seconds) for all sentences in the *backward* FORMAT. The difference in the length of sentences in *forward* and *backward* formats, four and five words respectively, probably accounts for this difference in predicted sentence reading times. During the development of the regression model it became quite clear that FORMAT does not interact with any other variables.

9. Discussion

The regression model developed for the present data is a close relative of that developed by SSL for data from a much simpler experimental situation. At a first approximation, one can describe the present model as being derived from the old one by adding variables to take account of new processes arising from new demands posed by the more complex texts. Insofar as this description is accurate, the present experiment provides strong evidence of modularity of construction processes.

At the outset, the general degree of modularity that is demonstrated by the good fit of such simple linear regression models to this data is worth emphasising. In the current experiment, all levels of all factors occur at several different positions in various text modes and format, and, in different combination. In this respect the present model accounts for a far greater degree of freedom in terms of sentence positions at which these variables take a value, and in terms of the variety of their possible combinations. This is due to the increased number of modes in which texts were presented. Even in SSL's simpler design, the levels of MISLOAD occur at several different text positions. The definitions given to the variables all assume that the effects of the variables are independent of the history of processing, and therefore the position of occurrence in the texts. For example, MISLOAD may take the value 1 anywhere between the second and eighth sentence of a text and is assumed to have the same effect on reading time at all these positions. That the SSL model can be extended to model our data, with the addition of only two more variables, is strong evidence in support of the claimed modularity of construction processes involved in the representation of semantic structure of texts used in the MIT.

Apart from the general assumptions of these models, the modularity demonstrated by the continuance of most of the previous model's variables as constituents of the present one is even stronger than at first might be supposed. Take, for example, the observation that the NEUTLOAD function is closely similar in the two models. This is not merely a replication of the same effect in the same circumstances. In the earlier texts, NEUTLOAD was only ever positive on sentences about the first presented individual. This restriction was an artificial limitation of the two text modes used in that experiment. In the current experiment, NEUTLOAD takes all of its values except the highest on both individuals. So the fact that the NEUTLOAD function is little changed is a powerful generalisation of the observation that properties known of the currently referenced individual but unresolved of the other individual impose particular unvarying time costs wherever they occur.

How reasonable is the generalization that the old model continues as a subset of the new model? What does the absence of LOCALMIS and MATLOAD in the new model mean? And what does the difference in the two highest values of MISLOAD signify?

The MISLOAD function in the present model contrasts with that of the SSL model in that instead of being a linear function, at the two highest loads reading times are equal to the level of the MIS2 property load. Coupled with the observation that NEUTLOAD is little changed, this indicates that subjects were relying more heavily on the redundancy offered by the match features in this more complex task. We have already mentioned that as the number of possible intra-individual associations increase, so would the processing load, and therefore, reading times. The predicted model on MISLOAD reading times implies that the construction of a representation of intra-individual associations is constrained by other factors during the latter part of the text comprehension task. Subjects may simply be recruiting fewer associations between properties relying on just remembering that on a particular property dimension individuals have different attributes. As the dimension order was fixed, this strategy would be particularly useful during the latter part of the text which may account for the predicted drop in reading time at MIS4. We will return to this issue below.

LOCALMIS is selected as a variable in the general SSL model, its coefficient was larger in a model for P x P texts than in a separate model for I x I texts. We know from other experiments (eg, Levy 1989) which have used just P x P texts that the local processes associated with a positive value of LOCALMIS are more evident in processing texts in P x P than I x I mode. In P x P mode, mismatches are always identifiable on alternate sentences, whereas in I x I mode, subjects must wait for a fixed interval of four sentences to identify any mismatches or matches. The current experiment makes such identification even more difficult than in I x I mode because it renders unpredictable the point at which information about matching status becomes evident. Differences also appear in the details of the models of error frequencies (see Chapter 4) which support the observation that modes differ in their emphasis on information about matchtype structure.

How are we to interpret the impact of differences between modes on the coefficient of LOCALMIS? If we interpret LOCALMIS as process associated with a simple mnemonic strategy of representing mismatches when they occur (and are readily encodable as in P x P mode texts), then making mismatches more difficult to process (as for modes used in this study) would increase the time consumed by processes represented by LOCALMIS. So if the same processes have to be carried out in more adverse circumstances, then they should take longer. Since our model does not even predict a reading time coefficient for LOCALMIS processes, let alone predict an increase, it would appear that the correct interpretation is that when it becomes more difficult to apply these processes to mismatches they are abandoned. In other words, the processes associated with LOCALMIS though useful as mnemonic strategies when easily available are dispensed with when this is not the case.

What might these mnemonic strategies be? They are not merely detection of mismatches. The SSL and our models provide abundant evidence that mismatches are detected in the current task: if they were not detected, how could the load functions NEUTLOAD, MISLOAD and MATLOAD be so different?

If LOCALMIS is not to be interpreted as representing *detection* processes, the obvious alternative is to interpret it as representing *construction processes*. But not the construction of whatever is represented by MISLOAD, because those are cumulative processes. We interpret MISLOAD as representing the process of tying together the several properties of an individual by recruiting associations between them. Under this interpretation MISLOAD does not represent the construction of representations of mismatches as such: the mismatching determines *where* properties of the second individual need to be associated. Contrasting this with the representation of matched properties should help clarify this issue. If, for example, a reader learns that the second individual is large which happens to be the same as the size attribute of the first individual then she only needs to represent a single item "large". Now if the second individual is small the reader has to remember two different attributes, "large" and "small", and, *which* one it attributed to *which* individual; she has to construct intra-individual associations between the mismatched properties and their attribution to distinct individuals being described in the text. The representations are of the same type as those constructed by the processes represented by NEUTLOAD. This line of thought suggests that LOCALMIS may, in contrast with MISLOAD, reflect processes associated with the representation of the *matchtype structures per se*.

The SSL recall error model shows that subjects in their experiment were representing higher level information of a matchtype structure of texts. It contained a variable NMAT which reflected the number of matched property dimensions in a model. This feature will be shown to function in the representation and to influence relative frequencies of complex errors of matchtype structure. In the current experiment the evidence for the existence of this feature in the representations subjects construct is mixed: the relevant patterns of complex error frequencies indicates that the strategy of representation of NMAT is affected by mode, and therefore, is often not represented. Accordingly the absence of LOCALMIS in our reading time model is interpreted as the result of subjects not engaging in the representation of higher order features of match structure. There are two possible alternative explanations for this. First, unpredictable switches of reference divert necessary resources from such processing. Second, a more interesting explanation, the representations underlying NMAT are parasitic on temporal ordering information, and this information is obscured by the referential switching. We return to this issue in Chapters 4 and 6 dealing with recall errors of the present and the next experimental studies respectively.

The absence of MATLOAD from the present model indicates that subjects are content to rely on the redundancy provided by the matchtype structure representation to a greater degree than in the earlier experiment. In particular, when the two individuals match on a dimension it is not necessary to integrate the property into either representation since it is sufficient to remember which of the two possible properties actually occurred in the text. Subjects in this experiment appear to have been more willing to rely on this representational short cut. The definition of MATLOAD in the SSL model provides further support for this explanation. In that model, MATLOAD takes a value only after a mismatch (other than the introducer) is encountered. This indicates that subjects in the SSL experiment were also relying on this sort of redundancy. Reading time results of the next experiment enable us to study further the nature of processes represented by MATLOAD, and, we will return to this issue in Chapter 5.

Even with these caveats, the overlap between the old and new regression models represents a high degree of modularity of processes. What do the additions to the model tell us about the processes involved in referential switching? Firstly, they tell us that these processes interact little with the other processes modelled. The combined processes represented by CONTOUR and FOREGROUND are assumed to be unaffected by the matched, mismatched, or unresolved status of the attribute when reference is switched. Secondly, they tell us that switching reference unpredictably to referents with complex specifications is slower than to referents with simple specifications, where complexity is defined in terms of known number of properties. This relationship between complexity and time is roughly linear. SSL showed that predictable switching does not cost time. Thirdly, they tell us that when an unpredictable switch is a switch from *reference* to one individual to *introduction* of another individual whose identification is predictable, processing is actually saved which probably reflects the determinacy of texts in employed in the MIT. Finally, it shows that the processes associated with the assignment of resolution of the current referent is independent of the other individual in the background.

Sentences of texts in *backward* format take longer to read probably because their greater length and unconventional format. This effect is independent of processes related to shifts in reference or construction of semantic structure. This is evidence in favour of the modularity of construction processes and their generality in terms of being independent of a particular property dimension order. However, this issue is a lot more complex as the next study reveals, and we return to it in Chapter 5. In the next Chapter we present further analysis of reading time data which reveals the role of rehearsal processes in working memory during text comprehension.

Chapter 3

1. Introduction

In this chapter we investigate the role of rehearsal in working memory during text comprehension. We present a regression model which provides an account of the effect of rehearsal of individuals' property attributes on reading time. This analysis is based on syllabic length, and the model provides further insight into how readers' rehearsal strategies are affected by processing load imposed by unpredictable switches in reference.

Analyses of recall error data shows how the construction of representations of individuals is affected by modes. Details of these findings are given in Chapter 4. The difference in this structural organisation between individuals provide an excellent opportunity to explore the effect of rehearsal on reading time. More specifically, reading time differences between modes enable us to factor out the different effects that the rehearsal of referenced and non-referenced individuals have on reading times. The model presented here gives a better overall account of the observed reading time differences between sentences, within and between modes, thus giving a very good indication of the complexity of the involvement of rehearsal processes in working memory. On the basis of the model's prediction we give an account for the role of the Acoustic Rehearsal Loop and its counterpart Articulatory/Acoustic Storage (ARL/AAS) system in human text processing. Much of the work presented here is at a very exploratory stage, and requires further research in order to complete our understanding of the role of ARL/AAS system in working memory during text comprehension. On the other hand the research reported here illustrates the benefits of our methodological approach to a better understanding of psychological processes of knowledge representation.

Baddeley (1986; Baddeley, Lewis and Valler 1984) has shown how a number of different storage systems are involved in working memory. The role of the ARL/AAS system is particularly relevant for interpreting the semantic ordinal effect in terms of rehearsal processes. The notion that rehearsal processes make some contribution to reading time, the semantic ordinal effect in the present case, is uncontroversial. Any text or discourse comprehension task would require a process which reviews what is already known, partly so that new information can be encoded in a more coherent manner, thus maintaining overall consistency. More formal (computational) attempts at modelling discourse understanding usually necessitate similar sorts of continuous checks to maintain overall internal consistency and coherence. In earlier theories of representations, such as frame (Minsky, 1975) or scripts (Schank and Abelson, 1977), this assumption is implicit. More recent theoretical work such as the Discourse Representation Theory (Kamp 1979, 1989; Asher and Kamp 1986) and Situation Semantic Theory (Barwise and Perry 1983, for a general introduction to a theory which has been through a number of major changes since) make explicit provisions for these sorts of review processes. More practical approaches to cognitive modelling as a basis for knowledge based implementation (typically for expert systems) make the most compelling case for processes (see Barnard, 1987 and Barnard, Wilson and MacLean, 1988) similar to ones observed in list learning (eg Baddeley 1966) or simple inference making tasks (Clark and Haviland 1977).

Some rehearsal processes would also be implicated during a shift in reference. We have already shown that time taken to read incoming information about an individual is not affected by what is known about the previous individual. In the present study there is some evidence that not all the increase in reading time can be accounted for by the foregrounding processes. Some of it has to be accounted for by rehearsal processes that reflect the memory processes affected by the *syllabic* length of property attributes of either individuals. There are two possible rehearsal processes connected with a switch in reference. First, subjects need to refresh already known information about the newly referenced individual. This is necessary if new information is represented in association with already known attributes of an individual. The building of associations facilitates a solution to the binding problem. Second, when reference is switched subjects need to spend some time on rehearsing the attributes of the now non-referenced individual. It is important to note that these rehearsal processes are not regarded as similar to those postulated to account for findings based on the relatively simple task of list learning by rote. Baddeley's ARL/AAS system is based on evidence from list learning tasks, which casts the rehearsal processes as independent of semantic processes, and can even be construed as functioning in competition with semantic encoding. Findings based on reading times presented in Chapter 2 provide ample evidence to suggest that the MIT cannot be treated as equivalent to a simple list learning task. For example, there are no 'primacy' or 'recency' effects (see Wickelgren, 1977, for a general review of this recall phenomena in short term or working memory). The referential structure makes it a more sophisticated task involving the construction of semantic structure in representations, utilised to solve the binding problem.

1.1. Rehearsal processes in MIT

From the previous section it is clear that, the semantic ordinal effect cannot be totally explained in terms of semantic processing. Processes associated with articulation also seem to contribute to reading times. The present analysis enables us to factor out the contribution of rehearsal processes during text comprehension. Though findings based on list learning tasks suggest that articulatory rehearsal and semantic processing (Baddeley, 1986; Wickelgren, 1977) are mutually exclusive, the present study provides very strong evidence in favour of extending the theoretical limits of the involvement of ARL/AAS to more complex tasks. Our interpretation of the semantic ordinal effect in terms of cognitive processes, supports the view that the ARL/AAS system plays a role in *semantic processing*.

In the current task, to remember individuals' property attributes, subjects may exploit the sequential properties of the ARL/AAS system to group properties of an individual by rehearsing them in adjacent positions, rather than in order of presentation. For example, a reader may group properties presented in P x P mode, in an I x I mode. This grouping may precede the setting up a more durable representation based on semantic structure. So, initially, for a particular text mode, a subject may hold the attributes "large" "red" and "square" in an ordered mental list and construct associations between them only once reference is switched to the other individual. A switch in reference is also likely to involve rehearsal processes associated with foregrounding of the known properties, if any, of the newly referenced individual. If either or both of these is the case then differences in syllabic length of properties describing an individual should be reflected in small but significant differences in reading times.

Whether articulatory rehearsal processes can account for reading time differences between text modes (in other words, differences in switches between referents) can be investigated with considerable ease in the present study. This is because the sequence of properties is not confounded with the predictability of switches between references. In the MIT there are at least two distinguishable sorts of orderings: the dimension ordering in which individuals are described (eg, shape dimension precedes colour dimension), and referential ordering (eg, the first individual is completely described before the second one as in I x I mode). From the detailed description of the MIT in Chapter 2 it is evident that these two orderings mutually determine the eight sentences in a text. In SSL the semantic structure is presented by texts with one constant dimensional order, and one of the two fixed sentence orders; in texts modes P x P and I x I, both of which, as we have noted, are highly predictable in terms of referential order. This overlap between orderings (which results in predictable referential switches) makes it very difficult to factor out the processing loads of articulation associated with reference switches and/or ‘runs’ of attributes referring to the same individual (that is, the absence of reference switches between sentences).

In this study both ordering sequences are varied. The effect of the *limited* alteration in the dimensional order (that is, *forward* and *backward* texts) has no significant effect on the semantic ordinal effect, and therefore the underlying construction processes. But altering and increasing the number of sentence orderings, that is modes, highlights other non-cumulative processes which account for part of reading time differences between SSL and our findings. In this study it is possible to develop a regression model predicting these processes because we can define the temporal order of the semantic structure independent of the order of sentence presentation. For example, in P x P mode the match structure of the second dimension is *always* presented at the fourth sentence and the referent is *always* the second presented individual, while in our experiment this information can be given at anywhere between the fourth and the sixth sentence, and, the referent can be either individual. Thus, switch in reference is effectively unpredictable. This enables us to develop models which factor out the effect of articulatory processes sensitive to effects of syllabic length, and *not* properties, on reading times. We show that the role of ARL/AAS system during text comprehension is determined by an interaction between the known properties of the newly referenced individual, and whether that individual's status, derived from observed differences in recall error patterns between modes, in the representation is defined as *primary* (somehow, central) or *secondary (more peripheral).* We return to this distinction in the next section and Chapter 4.

1.2. The involvement of ARL/AAS in the MIT

The distinction between primary and secondary individual in turn suggests ways in which the reading time regression model may be improved by extending the account given by independent variables. The distinction between primary and secondary individuals and the irregular sequence of changes of reference allows fresh possibilities for investigating the involvement of articulatory rehearsal in the Memory for Individual Task. SSL, using ANOVA techniques, showed that the net effects of word length were limited in their more constrained and predictable texts, and hence did not incorporate word length variables into their regression model. As pointed out in the previous section the present design permits a better examination of the role of articulatory rehearsal, and in particular its involvement in changes of reference.

How is the distinction between primary and secondary individual defined? In the MIT each text describes two individuals on four property dimensions. For analysis of reading times, it is necessary to define for each sentence of each mode, whether the referenced individual is treated as primary or secondary. We assume that readers begin by treating the first mentioned individual as *primary* and the *second* mentioned individual as secondary. However, if more information about the second individual is given before that of the first individual then readers switch to treating the second mentioned individual as primary, and the first mentioned one as secondary. This switch in primary/secondary definition is determined in each text mode at a specific sentence position. Examination of recall error data of texts by mode shows that for certain modes subjects have a higher tendency to confuse the identity of individuals and to make more errors on the first introduced individual. Typically, in these modes the reader learns the second property of the second introduced individual *before* learning the third property of the first introduced individual. This occurs in modes 3, 5, 6 and 7, which will be collectively referred to as 'mode group 2'. Hence, for individuals described in these texts modes the primary/secondary status of individuals is switched such that the *second presented* individual is treated as *primary.* For text presented in the remaining modes 1, 2 and 4, collectively referred to as 'mode group 1', there is no such switch. Observations based on other studies (Stenning, Patel, Levy, Nelson and Gemmell, forthcoming) which included extra modes have tended to support this distinction between primary and secondary individual based on the relative amount of known information of each individual at sentence four in any mode.

It is also possible that the difference in the shape of the MISLOAD function between SSL model and our model given in Chapter 2 (henceforth referred to as 'Model 1') is related to the primary/secondary distinction. Examination of the reading time residuals for regression Model 1 show that there is a recognisable pattern of correlation between the residuals and the predicted reading time coefficient of MISLOAD. The nature of this correlation varies according to mode, and whether reference is switched or not when MISLOAD takes a values other than zero. More specifically, the residuals show that texts in the two Mode Groups, apart from having differences in recall error patterns, also have different reading time patterns. It is possible that the differences in representation suggested by differences in recall error patterns between individuals is a consequence of differences in processing within working memory during the construction of representations.

The articulatory rehearsal loop (ARL) refreshes an acoustic/articulatory memory store (AAS). In this storage system the rehearsal time of items in the AAS is predicted to be a linear function of number of syllables rehearsed. This store decays as a function of time, so its capacity is limited by the number of items that can be rehearsed by the ARL before decay degrades them beyond recognition. Acoustic material can gain entry to the AAS directly; written material only through the ARL (Baddeley 1986). On the basis of this characteristic of ARL/AAS we can predict at least two reading time effects. First, reading time will increase with the number of syllables rehearsed. Processing of incoming material slows down as the subject stores the syllables in the ARL/AAS system.

The other relevant prediction is that processing associated with rehearsing syllables in the AAS may be speeded up as the number of syllables in the AAS increase. This would happen if the subject is reading material that is not stored in the AAS, while at the same time holding other material (eg, related to the non-referenced individual) in the AAS. We have already shown that processing a complex structure such as our stimuli texts involve more than one sort of process in working memory. The load of other memory processes together with the fact that syllabic information held in the AAS decays with time, is the basis for this prediction. As the number of syllables increase in the AAS, rehearsal must start sooner to avoid decay beyond recognition; the greater the number of items in ARL/AAS system the greater the likelihood of information loss since each item will be rehearsed less frequently in the rehearsal loop. In order to overcome this handicap it is predicted that subjects may accelerate the process of rehearsal. The acceleration is predicted for each syllable and thus it is *not* predicted that overall time devoted to rehearsal itself falls. In fact, that is expected to increase at the expense of less time devoted to processes associated with other aspects of text comprehension. However, it must be stressed that the acceleration does not necessarily *have* to take place: Subjects may judge that processes other than the one associated with the rehearsing the contents of AAS are more important at certain stages and in certain text modes. The important point is that subjects must choose either to return sooner to the ARL/AAS system as the number of syllables it holds increases or lose material held in there. The model presented here shows that the choice is determined by a number of different aspects of the semantic structure of texts and switches in reference.

These two predicted effects on reading times are the main bases for our study of the involvement of ARL/AAS system during the processing of texts used in this experiment. The predictions are not mutually exclusive. Both effects may be present at various stages during the construction of representation. The following are the six major questions about the role of articulatory rehearsal during text processing that we intend to address:

(1) We know that reading time is strongly predicted by the identity of the referent and the number of properties known of that referent. To what extent does rehearsal processes account for the increase in reading time related to increasing knowledge of an individual, that is the referent? How much of the Semantic Ordinal Effect can be explained by rehearsal phenomena?

(2) Is the rehearsal confined to syllables of the currently referenced individual or does rehearsal of the other individual (in the background) also takes place? If, to a certain extent, rehearsal of knowledge about both individuals occurs, then factoring out the respective reading times contributions of the referenced and non-referenced individuals should reveal the complexity of the ARL/AAS system in text processing. This in turn should help us understand better the role of articulatory rehearsal in non-list based semantic processing in working memory.

(3) Does the subject rehearse the entire accumulated description of an individual, or only that part which has accumulated since the last switch to the current reference? Or, perhaps there may be a difference between the time spent on rehearsing

attributes accumulated before and after the last switch. If this is the case, then it would support the view that the construction processes are affected by switches in reference. This question also enables us to determine the role of rehearsal in terms of other processes of construction of representation.

(4) We know that matched dimensions attract less processing time. Is this partly because words specifying the same properties for both individuals are rehearsed less frequently, or is rehearsal independent of such semantic considerations?

(5) The effect, if any, of a switch in reference on rehearsal processes should also be considered. We have seen that changes of reference cause changes in reading time as a function of the known number of properties of the newly referenced individual. Are these changes in reading time accounted for by rehearsal of the descriptions of individuals? Does a change in reference necessitate rehearsal of words describing either the newly referenced, or non-referenced, or both individuals?

(6) We have already explained the reasons for making the distinction between primary and secondary individuals as a consequential effect of text modes. The predicted difference in the organisation of representations of these two types of individuals (as we will see in Chapter 4), may be explained by primary/secondary related differences in subjects rehearsal strategy. Does the distinction between primary and secondary individuals affect the involvement of the ARL/AAS system?

In the next section we briefly describe how independent variables which take into account syllabic lengths of words describing individuals were developed. A number of other aspects of the semantic structure and the modes of texts were taken into account in defining these variables. This made them sensitive to increases in the number of known properties of an individual, unpredictable switches in reference, the primary/secondary distinction, and whether the words described referenced or non-referenced individuals. Following a brief description of each sort of variable offered for selection by multiple regression technique, we will present the model and report some of the more interesting prediction is greater detail.

2. Syllabic effect variables for regression analysis

In order to investigate the above questions, the number of syllables of the new content word in each sentence was computed, and a running total of accumulated number of syllables describing each individual at each sentence was kept. Since the description of individuals was generated by random selection of vocabulary items given in Chapter 2 the number of syllables varied widely between texts. It is important to bear this in mind when evaluating the regression model. The model's predicted coefficients of syllabic variables are based on large variations between number of syllables and various sentence positions in texts. The model therefore accounts for the effect of syllabic rehearsal during text processing at a very general levels. This adds to our overall confidence on the findings presented here and conclusions drawn.

The syllabic count variables were used to define other variables to account for different sorts of loads of syllables. The full set of independent variables are described below. These variables are designed to enable us to answer the above questions, which we will show interact. Like any multiple regression technique the development of the model involved a number of exploratory stages. At each step new variables were defined or existing ones modified in response to residual analysis feedback. However, here we do not propose to take the reader step by step through the development of the final regression model. Instead the main relevant findings are summarised in the section which is followed by a discussion.

The model presented here included all the variables that were selected by Model 1 and two new sorts of variables to take account of the primary/secondary individual distinction, and, rehearsal of syllables. Residual analysis revealed reading time differences between reference switches to primary and secondary individuals.[4] To allow the model to factor out this effect a new FOREGROUND variable was defined. This variable, PRFOREGROUND, characterised the number of *properties* on primary individual to which reference has been just switched. The definition of PRFOREGROUND is that it is a non-cumulative variable which takes a value at all except the first contour switch to a primary individual. The factor is expressed as dummy variables PRFORE1, PRFORE2 and PRFORE3. Each had a value of 1 if PRFOREGROUND's value corresponded to the number of properties of the primary individual being foregrounded when a switch in reference occurs, otherwise it is 0. Note that given our criterion for the defining primary and secondary individuals PRFORE1 has the same definition as FORE1.

The second set of variables are the ones characterising the number of *syllables* accumulated in the description of individuals, all of which have 'SYL' as a suffix. All these variables take as values the number of syllables in the description of an individual accumulated thus far, including the current word. In all cases except variables terminating with -RUNSYL, the accumulation of syllables is from beginning of each text. With -RUNSYL variables, the accumulation is from the last change of reference. In all cases values are zero if the current sentence does not fit the characterisation. As we have mentioned above independent variables defined to factor our the effect of syllables on reading times can be characterised to take account of a number of different aspects of texts used in this experiment. Here we define variables to take account of three basic different aspects:

(1) Whether the individual is currently referenced, referred to as REF, or not, NREF.

(2) Whether the individual is defined as primary (PR) or secondary (SC) according to the criterion given above.

(3) Whether the current sentence refers to the same individual as the immediately preceding sentence or whether it switches to the other individual (SW). That is, no

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[4] The primary/secondary distinction was also used to distinguish other cumulative load variables. However, MISLOAD and NEUTLOAD factors so defined were not selected by the model and therefore are not described here. See the Results section for further details.

switch in reference occurs and the corresponding value of CONTOUR is 0, or there is a switch, and CONTOUR has a value of 1. Presence of SW in a variable name denotes a switch.

All these bivariate definitions, including SYL and RUNSYL, can occur in various combinations some of which are mutually exclusive, and other not. Below we give a full description of only that subset of all possible combinations selected by the regression model. Apart from the PRFOREGROUND, the model selected the following syllabic variables:

(1) REF_SC_SYL: referenced secondary individual.

(2) NREF_SYL: non-referenced individual. This could be either primary or secondary individual in the background.

(3) NREF_PR_SYL: non-referenced primary individual.

(4) NREF_SW_SYL: non-referenced (primary or secondary) individual after a switch in reference at the current word. It describes the syllabic length of words describing the individual referred to in the previous sentence.

(5) NREF_SC_SW_SYL: non-referenced secondary individual immediately after a switch in reference at the current word. That is, when the secondary individual is no longer in the foreground.

(6) REF_PR_RUNSYL: referenced primary individual denoting syllables accumulated since the last reference switch.

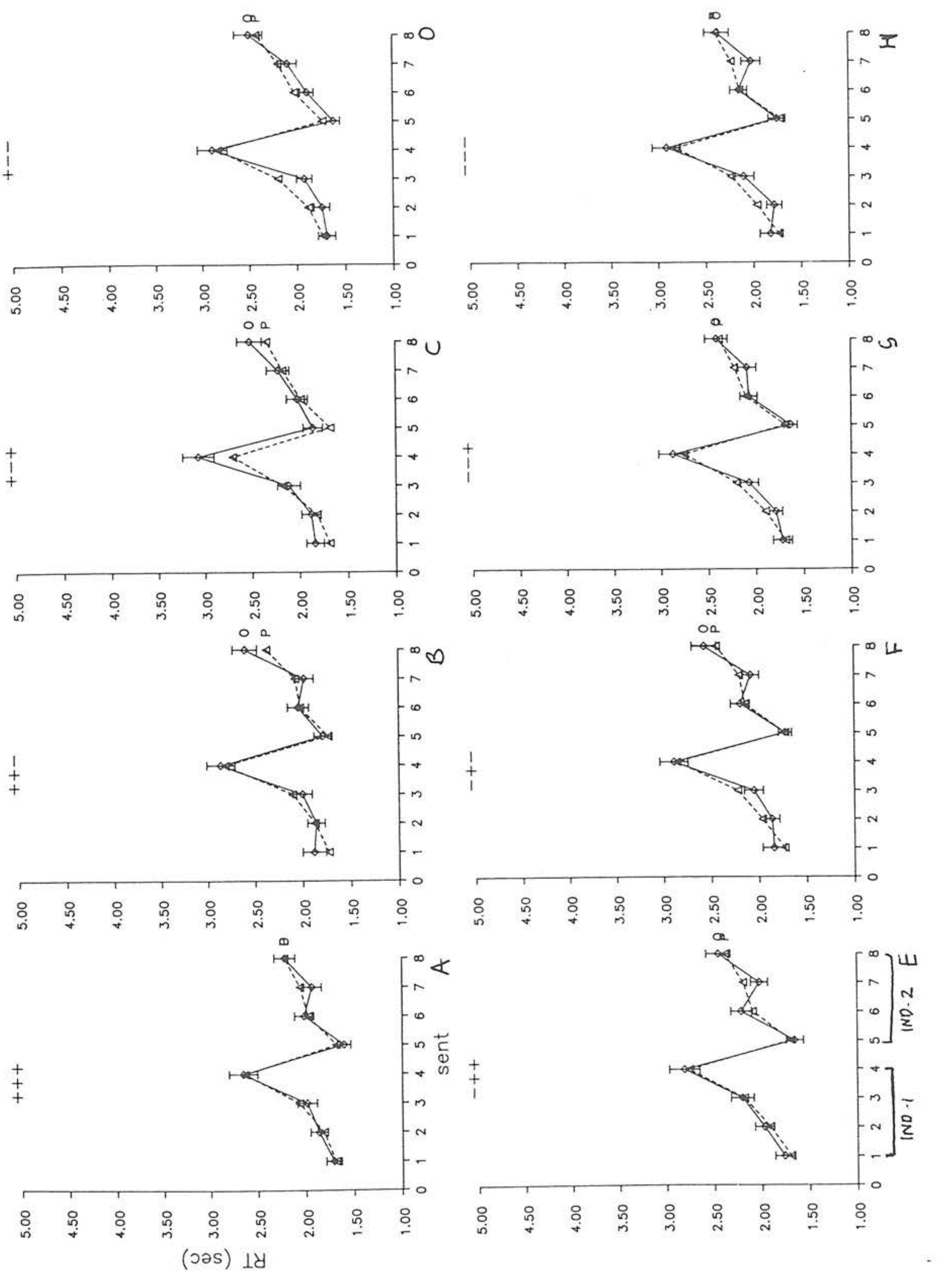
(7) REF_SC_RUNSYL: referenced secondary individual denoting syllables accumulated since the last reference switch.

(8) REF+NREF_SYL: total number of syllables at any word positions since the beginning of the text.

3. Regression model results

Table 1 shows the regression model developed to incorporate an account of syllabic effect, and the primary/secondary individual distinction. Figures 1 and 2 show the observed and predicted reading times for the new regression model at each sentence position and matchtype structure, and mode, and for all modes combined. Introduction of syllabic variables and the distinction between primary and secondary individuals improves this model's overall prediction of the factors' contribution to observed reading time. Comparing graphs in Figures 1 and 2 with those in Figures 2 and 3 in Chapter 2 clearly illustrates this improvement in the fit between the predicted model and the observed data.

Figure 1: Observed and predicted reading times of predicate by matchtype



Unfortunately we are unable to report the exact percentage of variance that the model accounts for, or the goodness-of-fit between the predicted model and the observed data due to a lack of suitably powerful computing facilities. This improvement is achieved without major changes to the MISLOAD and NEUTLOAD functions. The intercept is decreased by 0.17 seconds which indicates a reduction in the unexplained variance. Next we will consider in detail the similarities and differences between this and the reading time model presented in Chapter 2.

Table 1

Summary of reading time Model 2 with primary distinction and syllabic variables.

Variable	Coeff.	Standard Error
Intercept	1.09	
FORMAT	0.22	0.03
NEUT1	0.24	0.06
NEUT2	0.21	0.08
NEUT3	0.35	0.10
NEUT4	1.07	0.15
MIS1	0.46	0.06
MIS2	0.68	0.07
MIS3	0.69	0.08
MIS4	0.60	0.13
CONTOUR	-0.28	0.09
FORE1	0.22	0.07
FORE2	0.42	0.11
FORE3	0.59	0.15
PRFORE2	0.80	0.17
PRFORE3	1.00	0.17
REF_SC_SYL	-0.15	0.03
NREF_SYL	-0.18	0.03
NREF_PR_SYL	-0.06	0.02
NREF_SW_SYL	0.14	0.02
NREF_SC_SW_SYL	-0.41	0.04
REF_PR_RUNSYL	-0.12	0.02
REF_SC_RUNSYL	-0.06	0.02
REF+NREF_SYL	0.15	0.02

Key: REF=referenced, NREF=non-referenced, PR=primary, SC=secondary, SW=switched reference, RUN=syllables accumulated since the last switch in reference.

The coefficients for the levels of MISLOAD decrease by 0.05 to 0.06 seconds uniformly. The coefficients for the levels of NEUTLOAD decrease by 0.04, 0.18, 0.32, and 0.23 seconds respectively, indicating that some of the increase in reading time associated with NEUTLOAD can be explained by articulatory rehearsal. Nevertheless, the overall shape of the NEUTLOAD function remains unaltered, and in particular, the large increase in reading time when NEUTLOAD is at a maximum is, if anything, relatively enhanced by factoring out word length effects.

The MISLOAD and NEUTLOAD functions are unaffected by the primary/secondary distinction: that is, the variables distinguishing loads on primary and secondary individuals do not get into the final equation. Differences do appear for MISLOAD factor when the primary/secondary distinction is introduced into Model 1, but these differences disappear when the syllabic variables are also introduced into the equation. Therefore, the explanation of the contrast in shape of the MISLOAD function between SSL's model and Model 1 cannot be explained in terms of the primary/secondary distinction. In which case the original explanation that the predicted curve reflected the subjects greater reliance on match-type information is retained.

Changes also appear in FOREGROUND in the new model, and as indicated by the selection of PRFORE2 and PRFORE3, this function is different for switches of reference to primary as opposed to secondary individuals. There is an interaction between primary/secondary status and amount known about the individual to which reference is switched. Coefficients for switches to primary individuals (PRFOREGROUND) with 0, 1, 2, and 3 previously known properties are -0.28, -0.06, 0.52 and 0.72 seconds respectively. Coefficients for switches to secondary individuals (FOREGROUND) with 0, 1, 2, and 3 previously known properties are, -0.28, -0.06, 0.14, and 0.31 seconds respectively. The relevant FOREGROUND coefficients predicted by Model 1 for switches to either individual with 0, 1, 2 and 3 previously known properties are, -0.18, -0.3, 0.22 and 0.67 seconds respectively. Hence, addition of syllabic variables to Model 1 has decreased the coefficients for switches to secondary individuals, with greater decreases for more specified secondary individuals. But adding syllabic variables has actually increased the coefficients for primary individuals with two or three known properties.

This increase in reading time as a function of number of properties is accompanied by differential syllabic effects for primary and secondary individuals *after* a switch of reference. On switching reference to a primary individual of which two or three properties are already known, there is an *increase* in reading time as a function of number of *properties* known. At the same time there is a *decrease* in reading time as a function of number of *syllables* in the description of that individual. We will now describe these syllabic effects along with others, in more detail. In the following all references to predicted coefficients for syllabic variables describe the effect of single syllables on reading time.

The findings with regard to syllabic variables are summarised in Table 2. We will initially describe syllabic variables in terms of the combined coefficients per syllable, before discussing the interpretation of these effects in terms of rehearsal and other processes.

Table 2

Summary of syllabic effects in Regression Model 2 (centiseconds)

These coefficients are for each syllable of description accumulated since the beginning of the of text, on referenced and background individuals, by continuity of reference and by primary/secondary individual.

	Referenced		Non-referenced	
	Primary	Secondary	Primary	Secondary
Reference *continued* from last sentence	15.53/3.22*	15.53/9.53*	-9.07	-3.16
Reference *switched* since last sentence	15.53/3.22*	0.04/-5.96*	5.40	-29.73

Note: In cells marked * there is a difference in the coefficients for the referenced individual's syllables accumulating before the current reference was established (shown on the left), and those accumulating since (shown on the right).

In the development of the model, there was no indication that syllables in the description of matched dimensions are treated any differently from any other syllables. Referenced and non-referenced (background) individuals do behave differently with regard to syllabic effects. This difference interacts with the primary and secondary status of individuals, and with whether reference continues from the previous sentence or has switched. Positive syllabic effects occur predominantly on referenced objects, both primary and secondary individuals showing the same syllabic effects for syllables accumulated before the current reference is established (15.53 centiseconds per syllable). Hence, for both primary and secondary individuals, syllable length of words describing individuals presented prior to the last switch in reference contribute the same processing loads. But more reading time per syllable is predicted for those accumulated on the secondary individual after the last referent switch to that individual. The predicted reading time coefficients are 9.53 and 3.22 centiseconds for the secondary and primary individuals respectively. Subjects are spending more time on rehearsing words describing a secondary individual.

For syllables accumulated on non-referenced individuals, there are smaller negative effects, -9.07 centiseconds for non-referenced primary individuals, and -3.16 centiseconds for non-referenced secondary individuals. This suggests that subjects spend less time on articulating primary individuals in the background, than secondary individuals. This is probably because the construction of a primary individual's representation is more robust. Recall error analysis tends to support this conclusion.

This situation changes radically with a switch in reference, and the changes are distinguished by the direction of the switch with regard to primary/secondary individuals. When reference changes from a secondary to a primary individual, positive syllabic effects are still observed for the newly referenced primary individual (15.53 centiseconds per syllable), but very large negative effects appear for the now non-referenced secondary individual (-29.73 centiseconds per syllable). This large negative effect, as was mentioned above, is partly offset by predicted increases in reading time due to the process of foregrounding. This is a function of the number of known properties of the individual to which reference is switched. When reference changes from a primary individual to a secondary individual, unlike for the switch from secondary to primary, the positive effects on the newly referenced secondary individual all but disappear (0.04 centiseconds per syllable). On the other hand and also in contrast to a switch from secondary to primary, a small positive effect for the now non-referenced primary individual are observed (5.4 centiseconds per syllable). The difference in the predicted syllabic effects between switches from and to primary and secondary individuals is the clearest evidence, so far, to suggest that reading time spent on rehearsal is determined by other aspects of the MIT. Articulatory rehearsal, in more complex tasks such as the resent one under study, is partly influenced by other, semantic related, construction processes involved in text processing. We will discuss this in more detail in the next section.

4. Discussion of reading time regression model

Model 2 shows that the largest positive syllabic effects on reading time are for syllables of words describing referenced individuals accumulated *prior* to the establishment of the current run of references. Secondary individuals also show considerable positive effects of syllables accumulated *since* establishment of the current reference. We interpret these positive effects as due to articulatory rehearsal.

We must consider the possibility that some other characteristic of the vocabulary correlated with number of syllables is responsible for these effects. If only positive effects of word length were observed, then the most obvious characteristic correlated with length, namely frequency, might explain the effects. Longer words in this vocabulary are less frequent. The properties of individuals named by less frequent words may take longer to integrate than those named by more frequent words. However, the regression model enables us to observe a more complex set of effects of word length, some of which are positive and some negative. To explain negative effects in terms of word frequency would require postulation of some lexical representation (non-articulatory in nature) with rates of decay inversely proportional to the frequency of lexical items. Reliance on such representations in working memory might lead to accelerations of reading time in direct proportion to the frequency profile of words in the description of non-referenced individuals. Final discrimination of this possibility from the articulatory rehearsal hypothesis must await experiments using this task with vocabulary sets controlled for frequency as well as word length, though it is already well known that the frequency explanation does not hold good for list learning tasks (Baddeley 1986). For the present, at least, the negative syllabic effects observed for non-referenced individuals are most obviously interpreted, as proposed above. That is, they occur due to readers' acceleration of reading in proportion to the amount of material about a non-referenced individual held in the AAS. With this interpretation in mind, the pattern observed *after* a switch in reference suggests an asymmetry in the role of rehearsal in processing the primary and secondary individuals.

When switching away from a secondary individual, a very large acceleration of reading of the primary individual occurs as a function of the number of syllables about the secondary individual held in the AAS. This seems to indicate that the memory for the secondary individual is particularly dependent on the ARL/AAS system. In contrast, when switching away from a primary individual (to a secondary individual), a small positive effect of the number of syllables in its description occurs. This strongly suggests that some processing of the primary individual (now the referent of the previous sentence) may continue *after* the change of reference is detected by the subject. This processing may be related to the 'parcelling up' of whatever representations of the primary individual have been achieved *before* diverting attention away to the construction of representation of the newly referenced secondary individual.

A picture emerges of rehearsal playing somewhat different roles with respect to the two individuals. Rehearsal of the primary individual is mostly rehearsal of items from earlier runs of reference to that individual, but when a run of references to the primary individual terminates some time is spent rehearsing what has just been learnt about it. The balance of rehearsal of the secondary individual is still toward rehearsal of syllables from references previous to the present run, but relatively more time is spent rehearsing words learnt in the current reference run than for a primary individual. When the run of references to a secondary individual terminates, reading accelerates in proportion to the number of syllables in the description of the secondary individual.

For the secondary individual rehearsal may involve relatively greater reliance on the ARL/AAS as a representation of item identity. For primary individuals, rehearsal may reflect subsidiary use of the ARL/AAS system. After a switch of reference, subjects may retrieve information about the current referenced primary individual from semantically based representations, and re-enter articulatory representations into the AAS in order to expedite subsequent processing. This is supported by the larger coefficients assigned to by Model 2 to PRFOREGROUND variable. Further, as we will see in Chapter 4, model of subjects' recall error patterns indicates that semantic structure representations of primary individuals are more highly integrated. There are several possible functions for rearticulating words for properties which are already represented semantically. One of the most plausible being the redirection of attention to that item (or items) to facilitate the process of integration with one presented in the current sentence, and with any subsequent sentences referring to the same primary individual. Another reason is that it allows the reader to exploit information about the temporal sequence in which each individual's attributes were presented in a text: articulating properties of an individual together, especially when they were not read together (as was the case more often than not in this study), plays a role in creating a representation of their semantic relation. The preservation of sequential information is a particular characteristic of the ARL/AAS system.

How are we to assess the possibility of relying on the ARL/AAS as a representation to span an interruption in a sequence of references? The mean run length of references for primary individuals was 1.94 (predicate/sentences), and 1.92 for secondary individuals. The mean reading time per reference (that is, one predicate of either primary or secondary individual) is 2.1 seconds. So on average the duration between the end of one run of references to an individual and the beginning of the next run of references to the *same* individual is about four seconds. Baddeley estimates the decay time of usable information in the AAS to be about 1.75 seconds. Furthermore, the evidence of the model is that readers are also using their ARL/AAS system in the processing of an intervening run of references to the other individual. Delays involved are rather long to be bridged by AAS coding.

We observe that the balance of rehearsal time is actually spent on rehearsing items originating before the current run of references. Combined with current estimates of decay rates, this suggests that items are often being retrieved from some store other than the AAS, and are being reentered into the AAS through the ARL. This raises questions about interpreting the strong negative effects of word length as hurrying to return to the loop before decay completes. Either some information (perhaps about sequence, for example) is retrievable from the AAS at greater delays than supposed, or these negative effects of word length must receive a different interpretation. Findings of the other study presented here (in Chapters 5 and 6) suggests that information about sequence may play a large role in the construction of representations.

5. Summary of implication of reading times Models 1 and 2

In Chapter 1 we stressed the particular advantage of the Memory for Individuals Task in that it provides us with two sets of data, reading times and recall errors. Each is analysed independently to give us insights into the sorts of cognitive processes involved during the construction of representations, and into the sorts of structures that are constructed to solve the binding problem. The Semantic Ordinal Effect is interpreted as reflecting the increasing semantic load due to an increase in the number and complexity of associative links recruited to bind attributes describing individuals. Model 1 factors out this semantic loads (reflected in sentential reading time differences) in terms of associations made on the bases of different sorts of information. Functions such as, NEUTLOAD and MISLOAD, are predicted to increase the time spent on recruiting possible associations in line with an increase in knowledge about the sort of information that they define. It should be noted that the important aspect of matchtype information is that the cognitive processes reflect loads due to the encoding of possible intra-individual associations, and not, due to the encoding of the simple fact that a pair of attributes of one dimension are matched or mismatched. It has been shown that the predicted reading time profile changes when the latter occurs. Hence, apart from revealing a general relationship between associative links and reading time we have also given valid reasons for any exceptions in the general trend.

Further, Model 1 gives a good account of the effect of unpredictable switches in reference on reading times. It shows how the processing load of a switch in reference is a function of the number of known properties of the newly referenced individual. Model 2 enables us to extend our understanding of the role of articulatory rehearsal in the comprehension of texts in the MIT. In particular it enables us to give a clear account of how the rehearsal processes are sensitive to the semantic processing of incoming information: the combination of unpredictable switches in reference and relative differences in the extent of each individuals' description has an effect on time spent on rehearsing individuals. The introduction of the distinction between primary and secondary individuals forms the basis for the predicted differences in rehearsal strategies due to the semantic structure of texts.

So the two main important predictions of the reading time models is the role of semantic information in determining the nature of recruited associations, and the processing distinction between primary and secondary individuals, for texts with unpredictable switches in reference. In Chapter 4 we show how these two aspects also play a major role in our explanation of the observed pattern of recall errors.

Chapter 4

1. Introduction

In Chapters 2 and 3 we presented models based on reading time data. These showed how the incremental rise in reading times, the Semantic Ordinal Effect, can be factored into three sorts of processing loads involved in the comprehension of simple texts, employed in the Memory for Individual Task. These processes are associated with the loads imposed by information about the semantic structures represented in the solution to the attribute binding problem, the loads imposed by unpredictable switches in reference and the contribution of articulatory rehearsal to reading times. In this Chapter we present the findings based on recall errors. We show how this data can be analysed to model the actual nature of the encoded representation. What is the structure of the representations involved in the human solution to the attribute binding problem in long term memory? In doing so we will also show how predictions of the reading time models are compatible with the saliency of the constructed representations.

The Chapter begins with a recap of the MIT and how it enables us to investigate the representations involved in the solution to the binding problem. After outlining the question that we expect our models of representation to address, we give a theoretical account of the sorts of representations that would suffice to solve the binding problem for the semantic structure of texts used in this study. This is followed by a section of a review of SSL findings and the introduction of the distinction between direct and indirect models of representations. In the results section we will present the minimum descriptive findings of observed recall error and explain how the predominance of certain sorts of recall error patterns reflects the non-lexical semantic structure of texts, which in turn motivates our approach to the modelling of the underlying structures of representations. Based on two different approaches, we present two sorts of regression models in this Chapter.

2. What do we intend to model?

Our intention was to model the structure of the underlying representation structures of solutions to the binding problem in the MIT. The MIT is designed to pose problems in the representation of the binding problem, which enables us to explore the processes and structure involved in its solution. The task is described in detail in Chapter 2. Pairs of individuals are described in terms of pairs of contrasting properties, which are either the same (matched) or different (mismatch) on a particular dimension (eg, shape, colour, etc). Given that both individuals are described on four property dimensions, subjects have to discriminate the actual properties between a large number of possible combinations; as mentioned in Chapter 1 there are 136 possible combinations of responses. Hence, it would be expected that the task of assigning the correct property attribute to the correct individual would prove to be a difficult one. And indeed, if the material was a meaningless combination of digits, the task would be extremely difficult. We address the question, what sort of information is employed by the subject in order to solve the binding problem in the MIT where the potential for confusion is particularly severe.

In the present task subject have a lot more background knowledge about the restriction on the range of possible situations to be remembered (Bransford and Johnson 1972). They also employ the meaning of the properties describing individuals, as well as, non-lexical information (Bruner 1986) about the relations between properties of the same dimension, for instance, whether they are matched or not. This knowledge is brought to bear on the binding problem through the recruitment of general knowledge associations between the properties of an individual. If this is the case, then we can make the assumption that when subjects make errors in recall, they are expected to display patterns that reflect the underlying structure in the representations. This assumption is supported, both by results from other studies (including the SSL, the results of which are given below), and by the fact that during menu aided recall the important factor is the correct assignation of a property to the appropriate individual.

What sort of representation in memory would enable the subject to perform the present task without making too many errors during recall? Here we present models of the structure of representation, which give us an insight into the effect of unpredictable switches in reference on the sorts of associations recruited in the solution of the binding problem. More specifically, as in SSL, the present model is expected to address the following issues in the representation of the MIT texts:

(1) The nature of the binding between attributes to define an individual. The degree to which the bindings are dependent or independent of each other.

(2) The manner in which attributes of each individual are distinguished in the representation. This aspect of the representation will motivate our distinction between primary and secondary individual. We show how they are predicted to obtain different representations.

(3) The models enable us to build on the account given by SSL of the relationship between recall errors and the underlying representations.

(4) The role of general knowledge which supports the recruitment of association between properties without appealing to unanalysable, contentless primitive links. Whether the representations include any redundancy designed to overcome the difficulty in solving the binding problem in the MIT.

(5) The compatibility between the predicted salience of the structures and the associated constructive processes. We show how individuals are represented in logically connected fragments.

Next we briefly consider alternative accounts of the representations involved in the solution to the binding problem.

2.1. Semantic network type representation

In Chapter 1 and 2 we explained why the semantic network based theories (such as Anderson and Bower 1973) fail to give a good account of the processes contributing to the observed reading times in the present experiment. The models in Chapter 2 and Chapter 3 which predict that as subjects learn about individuals the representations become increasingly elaborate support this criticism. Here we show how an account of the solution to the attribute binding problem does not have to appeal to a separate category of primitive links in the model of representation.

Anderson and Bower (1973) and Jones (1976, 1984) have both used cued recall success rates as a source of data to constrain theories of representation. Jones shows how the recall error data suggests a fragmented representation, and argues that these simple models give a good account of phenomena presented by Anderson in a semantic network framework. The fragments described by Jones bear a certain resemblance to the approach developed here. Both posit representations composed of independent, and mutually redundant elements. However, Jones' fragmented representations, like Anderson's semantic network based theory, is associationistic; associations between properties are held to be *formed* at the time of input. The generated fragments consist of associations between the members of *all subsets* of the presented pieces of information. However, our analysis, and that of SSL, suggests that associations are recruited from existing long term general knowledge, and these associations implement the binding between *selected* subsets of the elements of the structures represented. Unlike, the fragments posited by Jones ours are not independent of each other: they are logically connected to each other. This is the consequence of the fact that the construction of the representation is not directly dependent on the order of incoming information though as we will see, the results of the next experimental study suggest specific exceptions. These formal differences are echoed in the choice of material used in the respective experiments. Jones uses material with minimal internal semantic structure and few component parts. The latter, restricts the number of arbitrary generation of combinations that make up the fragments to render then tractable.

The MIT is designed specifically to study the imposition of semantic structure through general knowledge, and uses sizes of structure which would be intractable within the fragmentation framework. Further, our models give a strong evidence of redundancy which is not considered by Jones, and which is an important determiner of constructed representation structures.

2.2. Theoretical considerations of representation structures

In terms of knowledge representation, the question is what kind of information is encoded by subjects solving the binding problem posed in the MIT. Reading time models indicate that processes associated with information about semantic structures contribute substantial loads. We assume that these play a major role in the structure of the constructed representation. In particular we expect to show what parts are encoded independently of each other and what ones are encoded dependently. An understanding of this distinction would lead to a clearer conception of how the representation of elements of information is implemented. Both, the information input into memory, and the information retrieved from memory can be specified in terms of partially independent but related propositions and their truth values. Each type of error is a transformation from input to output, and each type is characterised by the sub-set of propositions which change their truth values. Errors therefore are assumed to reflect systematic deterioration of representation traces that can be 'unraveled' to reveal the nature of the underlying representation.

We conceive of memory as a data base of facts (or statements). Our concern is with a theory of how people represent situations which share structural similarities but can have different content. We assume that the data bases contain facts composed of a constant set of propositions or their negations. These propositions are referred to as 'features'. An example of a feature is, "shape and colour of the first individual". Such a feature can take values like, "square and red" or "square and green". Features can take a range of value in terms of lexical items employed to describe individuals in a text. Here we are only concerned with the *similarity* of these values between the presentation and response. Content effects are not analysed for reasons given in Chapter 1. For every feature in the set, either it or its negation appears in every data base, and their truth values contribute to representations. Data bases are related by sharing or not sharing the truth values of features. This approach is similar to the use of confusion matrices to characterise perceptual dimensions of similarity (eg, Miller and Nicely, 1955). Our application of these techniques to semantic encoding, where no prior linguistic analysis specifies our feature categories, requires us to generalise the logical formulation.

The aim is to find a set of propositions, possibly assigned different degrees of salience, which will explain the relative frequencies of different types of error in terms of which feature's truth values are preserved. Errors which change the values of many (and the more salient) of these propositions will be *less* likely to occur. Errors which change few (and the less salient) of these propositions will be *more* likely to occur. If we are successful in finding such a set of propositions, the set would characterizes important properties of the memory system analysed. Since we know what logical relations hold between propositions, we know whether a particular set is adequate to represent the information to be remembered. The set of proposition would also enable us to decide whether the information is the minimum necessary or contains redundancy. The constituents of a particular set would further reveal what aspects of the information are represented independently of each other. This functional characterization does not, of course, tell us how the independent features (propositions) are represented; this issue is not being addressed here, and, there is no *apriori* reason for them to be represented as proposition as defined in classical logic. From the logical structure of such a set of propositions we can tell whether we have adequately analysed a system's solution to any given knowledge representation issue. For example, we can show whether the logical structure of the set of propositions adequately represents the attribute bindings in the MIT. It also enables us to predict the relative frequency of error types: that is whether, in a system in which features' fates are independently determined, memory would display the error patterns observed.

What systems for representing binding should we consider as candidates for human performance in the MIT? In classical logic systems, two mechanisms are available for representing the co-instantiation of properties by individuals: constants and variables. From Fa and Ga we can conclude that some individual, a, is $F \& G$. On the other hand, from $x(Fx)$ and $x(Gx)$, where x is a variable, not a constant, we cannot conclude $F \& G$ unless the variable x is bound by the same constant. The occurrence of a constant such as a serves to resolve questions of which individuals have which properties directly. That is, it requires simple inferences such as, from Fa, and Ga, conclude $Fa \& Ga$. These types of resolutions will be particularly direct if we impose the added restriction that each represented individual has a unique constant denoting it (for example, either a or b in our limited case).

Direct resolution of relations between facts is therefore dependent on the same quantifier binding different predicates. Considerable inference from additional premises may be required to resolve relations between other predicates, and indeed, these may not be resolved by any information in the data base. As an example where resolution is possible but indirect, in a data base containing the axiom that there are exactly two individuals, the premises $x(Fx \& Gx)$, and $x(\sim Fx \& Gx)$, and $x(Fx \& Hx)$, can entail $x(Gx \& Hx)$, (as well as $x(Fx \& Gx \& Hx)$, and possibly, $x(\sim Fx \& Gx \& \sim Hx))$. These facts represent the relation between G and H *indirectly*. It is this contrast between *direct* and *indirect* representation of binding that will be explored further in the present study.

The distinction between constants and variables is only one way of illustrating the contrast between direct and indirect representation. A direct representation would also suffice if entry to the data base is restricted to conjunctive facts, containing a single quantifier, and either the predicate F or *Such a restricted representation of predicate F* would allow as simple and direct a mechanism for inference as does a constant. Our interest is in discriminating different computational architectures, and particularly in determining whether the human solution to the binding problem in this task employs structural devices which identify properties as belonging to an individual *without recourse to their* *content*, or whether the solution is an indirect one relying on inference from content. We will exemplify this contrast by considering purely direct systems in which all predications are unique constants with indirect systems in which all predications are of variables. Each has different inferential properties which are our main interest.

It is evident that in a direct representation a simple inference solves the binding problem, but this is at the expense of a regimented representational formats. Indirect systems necessitate less regimentation but at the expense of complexity of inference at the time of retrieval. Though this distinction has been developed in terms of contrasts between two representation systems they are not mutually exclusive. An account of the solution of the binding problem in human memory is likely to appeal to a compatible combinations of direct and indirect representations. Such a combination is particularly suitable for the encoding of redundant information. In general it is expected that there is a considerable indirect element to human solutions to the binding problem. This issue is important in elucidating the computational architecture underlying human memory. Direct systems are most naturally implemented in localist architectures while indirect lend themselves to implementation on distributed connectionist architectures (Levy 1989, and for a general introduction to research in this field see, Rumelhart and McClelland, volumes 1 and 2, 1986).

3. SSL model of representation features

Stenning, Shepherd and Levy (1988) developed a regression model which gives a good account of the relative frequencies of various types of observed recall errors. The model factors out the representations underlying memory into features which have independent fates in memory but which are logically related to each other. Each feature represents a fragmented fact about the individuals presented in texts. The model predicts probabilities of types of response to presented material. Responses which shares all features with presented individuals is completely correct and highly probable: responses which share few features contain many errors and are infrequent. The model has both direct and indirect features. Its direct intra-individual features are constants defined in terms of the order of introduction of stimulus individuals which tie together the properties of individuals. By order of introduction we mean whether the relevant individual is introduced first or second in a text. None of the constituents of predicted features are common to all features. For example, though all sentences refer to the profession of the individuals not all features have this as an explicit constituent. Instead, the direct features that fix reference through implicit contextual information (form) of individuals (such as the order of introduction) were found to be better predictors of observed error patterns.

These sorts of direct referential features are logically sufficient, that is, the minimum propositions necessary to represent the pairs of individuals. However, the model predicts that though necessary they are not sufficient to adequately model the observed error patterns. Additional inter-individual features representing the matching and mismatching of properties dimensions (eg, shape or profession, etc.) are necessary to account for error patterns. These types of features introduce an element of indirectness into the model: inference is required to use the information contained in these features. Here we intend to investigate whether increasing the indirect element apart from being sufficient to account for the observed error patterns might not improve the model's prediction of certain sorts of patterns. In order to do so we need to give an account of the manner in which direct and indirect modelling approaches differ in terms of the pattern of errors that each is likely to be able to accommodate. As we show below emphasises on either approach results in non-trivial constraints about what can be inferred about the structure of underlying representations obtained in the solution of the binding problem in human memory.

3.1. Differences between representation structures of individuals

Are the observed pattern of errors in SSL due to inadequate representations or retrieval processes, or a combination of both? Indirect systems cannot account for differences between individuals as identified by order of introduction or of recall. Since any fact can be exemplified by one or the other individual it is not possible to distinguish between differences in representation between the two. In direct models, a better remembered individual can be identified because we can distinguish between the number and saliency of features applying to each individual in terms of their order of introduction. However, this raises the important empirical question about what aspects of the cognitive processes are being modelled.

In the SSL data, order of retrieval differences were observed: the first recalled individual was significantly more often correct than the second recalled individual. The first recalled individual is highly correlated with the first presented individual (80% of the time). Their direct model accounted for this by predicting that the features representing the first recalled individual are more integrated. But the direct model does not address alternative explanation that the retrieval of the first recalled individual disrupts recall of the other individual's representations in memory. The question therefore is, are these effects due to direct representations, or do they arise from processes that take place during retrieval? In the SSL experiment, subjects freely recalled individuals in either order and so it was not possible to tell whether subjects were choosing to recall the individual remembered best or whether the process of retrieving the first individual was interfering with memory for the other one. In the present experiment, order of recall was cued to resolve this question.

3.2. Accounting for error patterns in terms of indirect features

The aspects of error pattern frequencies which most obviously require explanation in indirect terms are those which result from representations centered on the property dimensions as opposed to individuals. The matching status of the pair of individuals has already been mentioned. These features are incorporated in the SSL model to account for the high frequency of cases in which an error is made on both individuals *on the same dimension.*

These errors are referred to as, *polarity errors.*

Similarly, a feature corresponding to the number of matched dimensions was shown to be necessary to explain the fact that when single errors occur on two different dimensions, they are most often *complimentary* in direction (a mismatched dimension becomes matched along with a matched dimension becoming mismatched) rather than *homogeneous* (both dimensions going in the same direction).

There are other effects which SSL model does not account for adequately, and, which require representation of other facts about property dimensions. Cases in which polarity errors are on mismatched dimensions, *individual* polarity errors, are much commoner than on matched dimensions *property* polarity errors. An individual polarity error occurs when two individuals with the conjoint attributes, "red square" and "green circle", are remembered as, "green square" and "red circle". A property polarity error occurs when two individuals, "red square" and "red circle", are remembered as both "green". In both cases the matching status of the dimension remains unaltered, that is, matched or mismatched, but the properties are wrongly attributed. The difference in frequency of these two types of error cannot be explained simply in terms of matching status of features as formulated in the SSL model. The addition of extra features characterising property dimensions would be necessary to model these error differences. However, such differences in effects arise naturally from the behaviour of indirect features identified with existential propositions asserting the co-instantiation of several properties.

If indirect features prove to explain certain error patterns better than direct ones, then a completely indirect model should be preferred for the following reasons. We have already pointed out that indirect features make fewer claims about the involvement of structural solution to the binding problem. In the SSL model direct features appeal to notion of individuals as constants. Indirect features that replace such individual oriented (direct) features would represent the solution to the binding problem without having to appeal to any such constants; instead they rely on inference based on quantified facts.

Shared truth values together with other indirect information such as matchtype information would be recruited to represent a solution to the binding problem. Another advantage of the indirect approach is that the less use that a representation makes of structural solutions to the binding problem, the easier it will be to give an account of how its solution is knowledge rich.

In general, indirect solutions can prove to be logically intractable but in the restricted domain of the MIT this is not the case. The important question is whether such models can give an adequate account of the error patterns observed, and if so, what organisation is there among the features of such a model? The SSL model solves the binding problem directly through constants based on implicit contextual properties, order of introduction, rather than through explicit textual ones, such as, profession or nationality. In seeking indirect models of the representations in the MIT, we aim to show that this direct solution is not required to account for the observed frequencies of recall error patterns.

Finally, there are some effects in the SSL data which the current framework cannot account for by any statistical model based on either direct or indirect representations of binding. The most important of these effects is the observation that *single* errors on a property dimension are commoner on dimensions on which the individuals mismatch than on dimensions on which they match. For example, given two individuals mismatched on the colour dimension, "red square" and "green circle", readers make more errors in recalling one of them then when recalling two individuals with a matched colour dimension, "red square" and "red circle". The SSL model predicts frequencies of response types by analysing the *similarity* (or congruity) between stimulus and response individuals on the basis of shared and contrasted features. This modelling assumes symmetry of the similarity relation. That is, the likelihood of giving response A to stimulus B is assumed to be equal to the probability of giving response B to stimulus A. This strong assumption holds fairly well, as is attested by the fit to the data achieved, but it is violated by the present observation, which in psychological terms, can be seen as a response bias. That is, when in doubt during recall subjects are more likely to assume that both individuals were matched on a particular dimension. To explain this bias we need to appeal to the processes involved in the computation of response from the constructed representation of the stimulus. A further advantage of the indirect models developed here is that computational models based on them can explain this asymmetry under general assumptions. If a model has an existential propositions containing a single term variable (for example, *Fx*, that is, an indirect intra-individual feature), and there are no other propositions to establish that a mismatch exists (that is, *is not case) then by default it is taken as evidence that each of the* individuals has the same property. Thus, it takes evidence from at least two such features to establish a mismatch whereas a matched dimension can be established on the evidence of a single proposition. Under most assumptions about the effects of noise, incorrect judgements that dimensions are mismatched will result more often than their converse.

4. Issues about memory and cognitive processes

In this section we will place the present study within the wider domain of processing and representational issues in cognitive psychology. The inverse relationship between reading time speed and accuracy in recall is usually observed in much simpler tasks (examples include, Baddeley and Hitch, 1974; Hitch and Baddeley, 1976) than the MIT. SSL report that texts with slower mean reading times were more often recalled without any errors. However, this effect was not observed at a sentential level; attribute presented in sentences with faster reading times were not necessarily the ones which were the least well remembered. This global effect was weak and the results further support our assumption that the MIT is not equivalent to a simple list learning task in which such one to one correlation would be expected. Instead our assumption that, as readers learn more about an individual she constructs increasingly complex structures, the speed-accuracy tradeoff effect, if at all present, is expected to be a small one. Levy (1989) shows that for MIT texts the important predictor of errors is the interval between presentation and recall. In the present study we show that with the added complexity of processing due to unpredictable switches in reference the inverse correlation between reading time speed and recall accuracy does not hold even at a global level.

The immediate issues about knowledge representation raised by SSL and findings about the solution of binding in human memory presented here have already been compared with other models of representation (Anderson and Bower 1973; Anderson 1978, 1983; and Jones 1976). In the larger landscape of theories of memory, the present theory is a closer relative of schematic theories such as those emanating from Bartlett's (1932) approach (Bobrow and Norman 1975; Bransford and Johnson 1972; Schank and Abelson 1977). In the sort of natural text that these theories are applied to, the episodic memory load is much lower because general knowledge structures are explicitly provided in the text which serve the same function as the recruited associations in the present theory. This associations constrain the number of possible interpretable combinations of properties which have to be distinguished in memory. It has been argued (Rumelhart, Smolensky, McClelland and Hinton, 1986) that a PDP implementation of schematic theories can overcome many of the problems associated with the enumeration of schemata encountered with frame based representations. PDP also seems a more tractable framework in which to approach the present problem of how values of orthogonal variables within schemata are bound (as Levy, 1989 shows). Our approach seeks to combine the ability of schematic theories to explain the influence of semantic interpretability on memory with the associationists' concern with the question about how novel combinations of experiences are registered.

5. Recall error results

In this section we present a descriptive analysis of the observed recall errors in this experiment. The design, methodology and the procedure have been described in Chapter 2. The scoring method is described in some detail since it reveals some important differences between modes of text presentation and recalled individuals. This is followed by a brief presentation of the log-linear analysis which gives an indication of the degree of intergration of represented individuals. Then we describe a the development of recall error models. For the purposes of comparison with the SSL error model, we first develop direct models of the current data. We pay particular attention to the order effects of presentation and recall, since these provide one way of differentiating direct from indirect models. We go on to develop indirect models of the current data, and to investigate remaining sources of lack of fit of these models.

5.1. Scoring method for recall error data

Recall scores were assigned by giving one point for each property correct of each individual. This requires assigning the individuals recalled (R-individuals) to the individuals presented (S-individuals). The introduction of recall cueing in an experiment which also introduced a variety of modes, revealed unexpected effects which affect this assignment. Subjects were cued to recall the individual introduced *first* or *second* in the immediately preceding text. Tabulation of recall scores by mode revealed that some modes were recalled considerably less accurately when scored as cued, but when scored with the best-fit[5] scoring method between recall and presentation this difference between modes disappears. Table 1 shows recall scores for each mode by the two criteria, namely best-fit and as-cued, separated into those cases for which the criteria agree, and those where they do not.

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[5] Recall was scored with recall individuals compared with stimulus individual in both possible orders of recall. The best fitting assignment (that is, where the difference between the stimulus and recall individual is the least) of recall individual to stimulus individual was chosen unless the two assignments were equally bad, in which case recall order was treated as the same as presentation order.

Table 1

Mean Recall scores by mode and by agreement vs. conflict of scoring criteria

	Where Criteria Agree		Where Criteria Conflict		
Mode	Frequency	Cued=Best-fit	Frequency	Cued	Best-fit
1	134	7.31	8	4.25	7.31
2	133	7.45	9	4.11	6.78
3	93	7.12	49	2.65	7.10
4	130	7.14	12	4.08	6.33
5	119	7.25	23	3.22	6.91
6	99	7.03	43	3.09	7.33
7	97	7.23	45	2.80	7.07

We interpret this effect of depressed recall performance in some modes as due to confusion of the temporal identity of the two individuals. It occurred about ten times as often (7.2% > 0.6%) in modes 3, 5, 6 and 7 as in the remaining modes. Further support for this interpretation lies in the relative accuracies of recall scored by the two criteria. In modes 1, 2 and 4, when the two criteria conflict in their assignments of presented individuals to recalled individuals, the mean score by best-fit is lower than in cases without conflict ($6.66 < 7.30$, $F = 11.62$, df. 426, $p < 0.001$) indicating that more forgetting has taken place. In modes 3, 5, 6 and 7 however, when conflict arises, the recall score by best-fit is as high as for cases without conflict ($7.13 = 7.16$, $F = 0.012$, df. 566, $p > 0.1$), indicating that subjects forgot the temporal identity of the individuals rather than their described properties. As pointed out in Chapter 3 these four modes are ones in which readers learn much about the second introduced individual early in the text. Analysis of these two groups of modes shows that confusion in temporal identity is reflected in differences between the representations of individuals, but before presenting these analyses, we report some descriptive analysis of recall errors which reveal some interesting features of the recall data. In the remaining analyses we adopt a best-fit criterion for scoring recall errors.

By this criterion, the mean recall score was 7.2%, and there is no significant difference in accuracy between the two groups of modes (Means 7.26, 7.15 respectively, F = 2.61, df. 992 p > 0.1), which suggests that higher reading times reflect more processing due to more complex associations being encoded in the representations that are prone to more errors during recall.

5.2. ANOVA results

All data is presented in terms of order of recalled individual as scored by the best-fit method. ANOVA's on the recall error results were carried out with subjects as the random factor, and modes (7 levels), formats (2 levels), recall individuals (2 levels, these will be referred to as R-individual 1 and 2), property attributes (4 levels - these will be referred to as A, B, C and D, according to their order of presentation), and matchtypes (8 levels) as fixed factors.

The mean number of unit errors per text was 0.77, standard deviation 1.04. Individual subjects' mean unit errors per text ranged between 0.25 and 1.27. There was a main effect of modes (F (6,54) = 3.44, $p < 0.01$). Texts in mode 2 were recalled with least number of mistakes (see Table 2). Recall errors by modes is not inversely correlated with reading time speed as would be expected if there was a speed/accuracy tradeoff. In fact, the correlation is significantly positive (r = 0.88 $p < 0.01$).

Table 2

Mean unit errors per text by mode.

Modes:	1	2	3	4	5	6	7	Total
Mean Errors:	0.61	0.55	0.87	0.86	0.82	0.83	0.83	0.77

There is a main effect of recall individual (R-individual). Subjects made significantly more errors on the R-individual 2 (F (1,9) = 22.95, $p < 0.005$). This is the case regardless of the presented order of individuals. Table 3 shows the distribution of single (error on one property only per individual) and multiple (errors involving more than one property per individual) for R-individuals *vis-a-vis* their stimulus position. As in the SSL data subjects made more multiple errors on R-individual 2 than on R-individual 1. However, this pattern was not replicated for single errors. Below we return to this difference and give an account of it in terms of different effect of modes, which is the basis for making the primary/secondary distinction introduced in Chapter 3. At this stage the observed differences in multiple errors suggest that recall of the first individual adversely affects subsequent recall of the other individual. The effect of recall order on errors is further investigated in the experimental study reported in Chapters 5 and 6.

Table 3

Percentage of single and multiple errors as a function of stimulus position and recall order of individuals.

	Single Error		Multiple Error	
Stimulus position:	First	Second	First	Second
R-Individual 1	21.4	22.9	4.5	4.8
R-Individual 2	20.5	28.0	10.1	9.1

There is a main effect of property (F (3,27) = 4.88, $p < 0.05$). Mean unit of errors on the first presented property (introducer) are significantly less than those on the other three properties (B, C and D). The mean unit errors for property A to D were 0.07, 0.10, 0.11 and 0.11 respectively.

There is a main effect of format (F (1,9) = 8.54, $p < 0.05$). Subjects made more errors on texts in *forward* format (0.88 mean unit errors per text) than in *backward* (0.72) format. Therefore, format has an effect on the frequency of errors but not on the percentage distribution of error for R-individuals in each format, as can be seen in Table 4. Errors on R-individual 2 are higher for both formats.

Table 4

Percentage of first and second R-individual errors as a function of format

	Forward	Backward	All Formats
R-individual 1	8.1	6.3	14.4
R-individual 2	10.5	9.3	19.8
Total Means	18.6	15.6	34.2

There is a main effect of matchtype (F (7,63) = 9.66, $p < 0.0001$). The frequency of errors increased with the number of mismatched properties. The mean unit errors were 0.27, 0.64, 0.71, 0.91, 0.69, 0.96, 0.89 and 1.08 for texts in matchtype 1 to 8 respectively. This effect is very strong and tends to be evident in significant interactions with other factors which suggests its strong involvement in the representation structure of a solution to the binding problem in human memory.

The interaction between mode and matchtype is significant (F (42,378) = 1.54, $p < 0.05$), as is the interaction between matchtype and format (F (7,63) = 2.62, $p < 0.05$). As might be expected, there is a significant interaction between matchtype and property (F (21,189) = 1.73, $p < 0.05$). There are significant interactions between matchtype, R-individual and mode (F (42,378) = 1.66, $p < 0.05$), matchtype, R-individual and property (F (21,189) = 2.16, $p < 0.005$), and matchtype mode and property (F (126,1134) = 1.47, $p < 0.005$). There is also an interaction between matchtype, property and individual (F (21,189) = 1.93, $p < 0.05$). Table 5 shows differences in errors which contribute to this particular interaction. All these interactions indicate the central role that matchtype information plays in representation of the binding solution during text comprehension in the

MIT. The development of the models of representation is expected to reveal more details of the involvement of matchtype, as will the second study reported in Chapter 6.

The interaction between format and modes is highly significant (F (6,54) = 5.21, $p < 0.0005$). There was no significant interaction between format and property which supports the conclusion drawn from the reading time results that the presented order of property dimensions does not affect comprehension in the MIT.

5.3. Property-oriented analysis

Next we will consider the correlation between performance on the same property of the two individuals. On a given property dimension, a subject could either make no errors, an error on R-individual 1 but not R-individual 2, an error on R-individual 2 but not R-individual 1, or an error on both (this type of error is also referred to as 'joint' error). Further, a property dimension may be matched or mismatched. Table 5 shows the percentage of errors classied in this way. The introducing property is always mismatched and hence, treated separately. This is referred to by the letter A and is the shape (eg, square or circle) property dimension in forward format, and size (eg, large or small) property dimension in the backward format. The other three properties dimensions, B, C and D, denote the order of the their presentation. These are collapsed across matched and mismatched dimensions since for both formats the distribution of error frequency is similar for all three dimensions.

Table 5

Percentage of first, second, and both R-individual errors as a function of matching status of property dimensions.

	Property A		Properties B-D	
	Matched	Mismatched	Matched	Mismatched
R-individual 1	-	2.3	3.8	7.5
R-individual 2	-	4.7	8.6	11.1
Both R-individuals	-	4.0	2.8	7.3

The likelihood of single errors on on R-individual 2 exceeds that of R-individual 1 on all properties (matched or mismatched). Generally, errors for the mismatched introducing property (A) are lower than those for other mismatched properties. Joint errors on A are lower than single errors on R-individual 2. This suggests that upto some extent the two individuals have independent fates in memory. However, the correlation between joint errors on mismatched properties is relatively high suggesting a degree of integration. This difference in percentage errors may be an effect of mode, and unpredictable shift in reference, an issue we will return to below. Matched properties B-D showed some evidence of correlation of errors between R-individuals 1 and R-individual 2 but it is not as strong as that for mismatched properties B-D.

5.4. Individual-oriented analysis

This analysis was carried out to look at the pattern of discrepancies between the R-individual and its target stimulus individual (S-individual). The percentages in Table 6 are based on data collapsed across format and mode. They show the frequency distribution of errors involving single properties and those involving more than one properties of individuals. For both individuals, single errors are the most frequent types of errors. Errors on property A are slightly lower than those on properties B, C and D though there is no discernible trend across the four properties. For R-individual 1 multiple errors have a tendency to include property C. However, for R-individual 2 multiple errors tend to include property B, though this effect is not as clear given the much higher incidence of multiple errors on R-individual 2. This difference in error patterns between individuals will be discussed in the next section where we present the findings of log-linear modelling analysis.

Table 6

Percentages of single and multiple errors across properties within individuals

		Property			
		A	B	C	D
Single Errors:					
	R-Individual 1	3.9	4.7	6.7	5.7
	R-Individual 2	4.3	6.9	6.7	7.0
Multiple Errors:					
	R-Individual 1	1.4	2.0	2.4	1.7
	R-Individual 2	2.4	4.0	2.8	3.3

5.5. Log-linear analysis

Log-linear modelling (see Bishop, Fienberg & Holland, 1974) of errors within individuals in SSL's data revealed a pattern of errors in which the least nominal dimension (D) which was always presented last, was most often involved in multiple errors. In that experiment, the property dimensions were always presented in the same order, and so it was impossible to separate differences between cohorts from effects of sequence. Separate consideration of error data of each individual for the two formats gives us the log-linear models presented in Table 7.

Table 7

Hierarchical Log-linear Models of Within Object Error Data by Format and Recall Order

	R-Individual 1				R-Individual 2			
	Model	X^2	DF	prob.	Model	X^2	DF	prob.
Forward:	A, BC, D	13.08	10	p=0.22	A, BC, CD	2.98	9	p=0.97
Backward:	A, CD, BD	8.73	9	p=0.46	A, CD, CB	8.36	9	p=0.50

The dimensions A, B, C, & D refer to the introducer, the second, third and fourth presented property dimensions of individuals. Analysis of the two formats of presentation in this experiment showed that the pattern of involvement in multiple errors is chiefly determined by the sequence of presented properties, rather than their property dimension; namely, shape, colour, texture and size. Notably, the errors on the introducer (A) are independent of all errors on all other properties in both formats. This replicates the effect noted by SSL and extends it to texts in another format showing that nominalness of a property is less important than the fact that it is an introducer. Just as the reading time analyses indicate that it is the *temporal* order of the properties of an individual that determines time spent, so it is the *temporal* order of an individual's properties which determines properties' involvement in multiple errors. Therefore, subsequent analysis is based on order of presentation of the properties.

6. Further analyses of recall errors

In this section we will describe how recall errors can be organised to reveal certain patterns in response. These error patterns highlight the influence of the role of matchtype information on recall errors. This analysis provides the basis for the development of regression models which predict the underlying structures of representations. First, the development of direct models will be described and the results compared with the SSL recall model. Then we will motivate and present an indirect model of recall performance and show how it gives a better account of the observed error patterns.

6.1. A classification of recall error types

Out of the 136 possible responses that can be made to a text describing two individuals with four attributes in the MIT, 20 were selected as most likely ones. (See Levy 1989 for a full account of the motivation for this selection). Between them they capture most of the sorts of recall errors observed in the MIT. Here we give a brief description of these error types, and Table 8 shows some examples of them for a single presented text.

Table 8

Some examples of recall errors types

Response Type	Response							
Correct	tall	happy	Polish	bishop	short	happy	Swiss	dentist
Single	**short**	happy	Polish	bishop	short	happy	Swiss	dentist
Individual Polarity	**short**	happy	Polish	bishop	**tall**	happy	Swiss	dentist
Property Polarity	tall	**sad**	Polish	bishop	short	**sad**	Swiss	dentist
Double Complementary	tall	**sad**	Polish	bishop	short	happy	**Polish**	dentist
Double Homogeneous	**short**	happy	**Swiss**	bishop	short	happy	Swiss	dentist

One unit of error is an error on one property of one individual. The simplest, and the most common, type of error is a single unit error. Single errors always alter the matching status of the property dimension - either matched to mismatched, or mismatched to matched. They can occur on R-individual 1 or R-individual 2.

If two unit errors occur simultaneously, there are several possibilities for their combination. *Polarity errors* in which two errors occur on a single property dimension, never disturb the matching status of their dimension. They are of two types. If the dimension is matched (say both individuals are "red"), then to recall them as both wrong, and hence still matched (both "green") will be termed a *property polarity* error. If the dimension is mismatched, (one "red" and the other "green"), then to recall them as both wrong, and hence still mismatched, will be termed an *individual polarity* error.

If the two errors are on separate dimensions, then they may be either *double homogeneous,* both match to mismatch or both mismatch to match, or *double complementary,* one of each. At the same time, for both homogeneous and complementary error pairs, both members of the pair may occur on R-individual 1, both on R-individual 2, or one on each individual.

As with error of matching status, polarity errors can occur in multiples; two individual polarity, two property polarity, or mixed polarity. Matching status errors can occur with polarity errors in a large number of combinations. See Table 9 for a list of all the relevant ones.

Finally, most possible error types fall into none of these categories, but also hold little obvious theoretical interest. They are rare in the data, and will be resigned to a miscellaneous category.

It should be noted that the definition of these types of errors make an underlying assumption about redundant information. If the observed pattern of errors can be categorised in term of matching status then it is assumed that matchtype information is encoded in the structures of representation of a solution to the binding problem. It is also assumed that the probability of a particular category of error is determined by the disruption it caused to the feature set. The higher the possible disruption, the less the likelihood of that error occurring.

6.2. Observed recall errors types

The SSL model was derived for data organised by recall order of the individuals, since as we have shown above that recall order is the main determiner of error pattern. The following additional analysis confirms that this choice of organisation of the data is appropriate. We adhere to the same terminology to refer to the difference between presented and response individuals; S-individual and R-individual respectively.

Further examination of the error patterns of the modes showed that the two mode groups (mode group 1 includes modes 1, 2 and 4, and mode group 2, the remainder) differed not just in the effects of applying the two scoring criteria but also in the distribution of errors between individuals. The frequencies of error in the same 20 categories used in the earlier study were scored both in S-orientation and in R-orientation. In R-orientation, mode group 1 showed a pattern similar to that observed by SSL in which more errors occurred on the R- individual 2 (92 > 48 asymmetrical errors, $p < 0.002$ two tailed). When the same modes were analysed in S-orientation, the second presented individual (S-individual 2) was worse recalled (90 > 50 asymmetrical errors, $p < 0.002$ two tailed).

Recalled texts in mode group 2 have more errors on the second recalled individual than the first (129 > 74 asymmetrical errors, $p < 0.002$ two-tailed), but they show the reverse pattern when the data is organised by presentation order, that is, the *first* presented individual is slightly, though insignificantly *worse* recalled (113 > 90 asymmetrical errors, $p = 0.12$ two tailed).

These effects of presentation order did not appear in the earlier study in which subjects were free to recall in either order. Although the present data is scored by best-fit, presentation and recall orders are much less correlated. There is both, an effect of recall order and presentation order, in the data from both mode groups. These effects suggest that this data should initially be analysed in both recall and presentation organisations.

There is only one possible correct response but many ways of making each error type (eg, single, individual polarity, etc), and subsets of possible error types vary according to texts with different matchtypes. The proportions of all responses, separated by mode groups, falling into each of the twenty response types (which included one correct and nineteen error types) are shown in Table 9, along with the proportion of all possible responses classified in each category. The latter values are the probabilities of a random recall falling in that response category averaged over all matchtypes of stimuli texts. The nineteen error types chosen are the maximal set of those described in the previous section which were sufficiently represented in the data. Their abbreviations are spelt out for reference.

Table 9

Proportions of observed and possible responses included in each response types

Abbreviation	Response Type	Observed		Possible
		Mode Grp 1	Mode Grp 2	(both groups)
corr	Correct	.583	.521	.001
misc	Miscellaneous errors	.018	.033	.569
sg1+	Single error on R-1 matched	.023	.019	.009
sg1-	Single error on R-1 mismatched	.052	.071	.015
sg2+	Single error on R-2 matched	.040	.051	.009
sg2-	Single error on R-2 mismatched	.094	.103	.015
ipol	Individual polarity error	.048	.087	.015
is1+	Individual polarity with ‘sg1+"	.002	.008	.016
is1-	Individual polarity with ‘sg1-"	.008	.011	.023
is2+	Individual polarity with ‘sg2+"	.002	.009	.016
is2-	Individual polarity with ‘sg2-"	.019	.017	.023
2cs1	Double complementary both on R-1	.008	.003	.019
2cs2	Double complementary both on R-2	.021	.013	.019
2cdf	Double complementary on R-1 & R-2	.034	.009	.032
dhs1	Double homogeneous on R-1	.006	.003	.019
dhs2	Double homogeneous on R-2	.015	.011	.019
dhdf	Double homogeneous on R-1 and R-2	.013	.013	.037
ppol	Property polarity error	.004	.008	.009
pp+s	Property polarity with single	.000	.005	.055
mirr	Mirror image matchtype structure	.006	.003	.049

For errors in both mode groups the possible probability of correct response is grossly underpredicted, while the number of observed error types subsumed under miscellaneous is a lot lower than possible. Overall single errors are more common than expected. This is particularly true for mismatch single error. Individual polarity errors occur more frequently than expected, and this is particularly the case in mode group 2. However, individual polarity errors with a single error on a matched or mismatched dimension were lower than expected in both mode groups. Though there was a roughly equal opportunity to make a double complimentary or a double homogeneous errors, the former kind were more common than the latter in mode group 1. This was not the case for mode group 2. Clearly, the distribution of errors types are to some extent dissimilar for different mode groups, which strongly suggests that the representation of the solution to the binding problem is affected by the sequence of presentation of individuals. This we took as further support for carrying out separate error analyses for each mode group. In the next three sections we describe the development of the linear regression model that predicts a set of features which account for the observed distribution of error types in different modes, or in other words, the observed patterns of confusion between presented and response individuals.

7. Development of direct models

The independent variables of the SSL regression model correspond to the accuracies with which the feature values of the stimulus individual are preserved in recall. The features of the successful model were selected from a set of possible candidates and revealed the organisation of the subjects' representation of a solution to the binding problem. Here we will describe the development of a direct model in some detail, and motivate our choice of variables.

Direct regression models for the error frequencies were derived in the same way as the SSL model, using the same candidate features and the same errors types. These features take a range of values. Pairs of represented facts are similar to each other in terms of their shared features. The greater the similarity between two descriptions the greater the likelihood of confusion in memory. Thus the most likely response will be the correct one. We have already described our assumption about structural similarities between representations of pairs of description. These features link the fate of different properties within an individuals (intra-individual features) and properties across same dimensions (inter-individual feature or matchtype dimensions). Our approach assumes a considerable amount of redundant information being encoded by the features represented. This is supported by the observed patterns in the error data presented in the previous section.

7.1. Candidate features for direct model

As we have already given a detailed description of features in the first part of this Chapter, details about the independent variables that correspond to each feature will be kept to the minimum.

All the features considered are functions which take predicates or conjunctions of predicates as arguments and return truth values. So the simple direct feature, *shape of the first individual recalled,* is a function which can take either "square" or "circle" as an argument and return true or false as its value. More complex features such as, *shape and the colour of the first individual recalled,* are also included. Such a feature can take any values, such as, "red square", "green square", "red circle" and "green circle". Complex features only return the value, true, if *all* the component predicates are true of the individual. A state of affairs, or a fact in the data base, is represented by arguments assigned to a set of features all of which are true of a situation.

The feature, *matching status of first dimension, DIMAMAT, is an example of an indirect* feature which takes one of the two values, 'matched' or 'mismatched'. The former predicate is true if both the individuals have the same property on a particular dimension and the latter is true if they are different.

The following is a summary of the sorts of features that were included as independent variables in regression models based on observed error frequencies predicting the structure of direct representations:

(1) Features integrating the individual, representing intra-individual links. All possible combinations of direct features ranging from A1 (being the first property of the first individual) to ABCD2, were entered for selection by the regression model. There were 30 of these.

(2) Features integrating the properties across dimensions (inter-individual links representing matchtype information). A feature was defined to describe the matched or mismatched status of property dimensions in text. There were 4 of these, DIMAMAT, DIMBMAT, DIMCMAT and DIMDMAT.

(3) NMAT is a meta-matching feature. It denotes the number of matched dimensions in a text. Any two presented and response individuals that have the same number of matched dimensions share values on this feature; those that do not, contrast with regard to this feature.

7.2. Fitting feature models of stimulus/response similarity

The above specification for features gave us 35 features. For regression analysis purposes these candidate features were treated as independent variables, and analysis was carried out to find out whether there is some combination of them which will serve as the basis for a representation that accounts for the frequencies of observed response types (see Table 9). Each stimulus description of both individuals is compared with its corresponding response. Most of the time there is no discrepancy between the stimulus and response, that is recall is completely correct. In the cases where errors are made, the 'incorrect' response is assigned to one of the error types given in Table 9. For each error type we can compute the probability of a relevant feature's value being true. That is, probability of a feature having the *same* value for both the stimulus and response individuals. Each feature has a determinate profile of congruence and contrast across the response types. For example, for a completely correctly recalled texts, all features have a probability of 1.0 of being congruent across presented and response individuals. As we mentioned earlier the probability of both having the same feature values is higher than the probability of differences in shared features.

Each feature thus contributes a measure of similarity between pairs of stimulus and response individuals. For the purposes of regression analysis features take values that are the proportion of responses in an error type for which the feature has the same value in both stimulus and response. Hence, each independent variables has values which corresponds to each feature's probability of congruence with a each type of response.

The dependent variable is the log of the adjusted frequency of each error type, which is computed as follows: the frequency of occurrence of a response type is adjusted by dividing it with the number of opportunities for its occurrence. The distribution of adjusted frequencies of response types is extremely skewed as a result of the preponderance of correct responses. Hence, the log of the adjusted frequency is derived in order to gives us a nearly normal distribution of log adjusted response type frequency.

Stepwise linear multiple regression analysis technique is employed to select a set of features which predict observed response type frequencies (see Draper & Smith, 1981; Kieras & Just, 1984). The regression coefficients of selected variables fitted to an equation are interpretable as measures of the salience of the features in determining the similarity of stimulus to response.

7.3. Direct models of representation features and discussion

The P2R Stepwise Regression routine of the BMDP statistical package (Dixon et al, 1968, 1983) was used to select all the models presented in this Chapter. Separate models were fitted to the two groups of modes. For each group, a model was fitted to the data scored in S-orientation and another fitted to the data in R-orientation. The models are summarised in Table 10. The contribution of each variable to $\mathbf{R}^2$ is significant ($p < 0.05$). Although subjects did not always obey the recall cueing, the actual frequencies of recall in and out of presentation order are similar for the two mode groups: 219 texts were scored as recalled in presentation order, and 207 in reverse order in mode group 1, and, 280 were recalled in presentation order and 287 in reverse order in mode group 2.

The models account for most of the relation between the frequencies of the main error types. The relations between single, individual polarity, complimentary double and homogeneous errors are well accounted for. Bearing in mind that the data is based on each text containing a different combinations of lexical items, the models' fit to the data is remarkable. As in SSL, these models consistently overpredict correct responses and underpredict miscellaneous errors types. There are other detailed differences in the prediction of various response types which however, are not very illuminating. Instead we will compare the differences between the models' predictions and the SSL model. This will reveals certain interesting differences in representation strategies due to differences in text modes.

Table 10

Summary of direct models predicting error frequencies from feature scores

Mode Group 1

S-Orientation $R^2 = 0.83$ deg. of fdm. = 9/74

R-Orientation $R^2 = 0.84$ deg. of fdm. = 9/74

Feature	Coefficient	Standard Error	Feature	Coefficient	Standard Error
Intercept	-2.89			-3.25	
DIMAMAT	0.77	0.14	DIMAMAT	0.77	0.16
DIMBMAT	0.36	0.10	DIMBMAT	0.46	0.10
ABC1	0.33	0.13	NMAT	0.20	0.08
AD1	0.29	0.12	ABC1	0.70	0.11
BD1	0.39	0.13	D1	0.58	0.10
C1	0.63	0.13	C1	0.31	0.14
CD2	0.34	0.16	D2	0.31	0.14
C2	0.51	0.15	C2	0.76	0.09
ABD2	0.53	0.10	ABD2	0.51	0.11

Mode Group 2

S-Orientation $R^2 = 0.89$ deg. of fdm. = 8/88

R-Orientation $R^2 = 0.90$ deg. of fdm. = 10/86

Feature	Coefficient	Standard Error	Feature	Coefficient	Standard Error
Intercept	-2.79			-3.27	
DIMAMAT	0.91	0.11	DIMAMAT	0.63	0.11
DIMBMAT	0.50	0.08	DIMBMAT	0.55	0.07
DIMCMAT	0.44	0.07	DIMCMAT	0.48	0.07
DIMDMAT	0.50	0.07	DIMDMAT	0.40	0.08
AB1	0.26	0.10	BCD1	0.60	0.13
BC1	0.32	0.10	AC1	0.38	0.09
CD1	0.59	0.08	BD1	0.25	0.11
BCD2	0.84	0.07	DC2	0.55	0.07
			A2	0.46	0.10
			D2	0.53	0.08

In mode group 1, both R- and S-orientation analyses leave out the matching features for the two last presented dimensions. NMAT appears in the R-orientation model with a similar coefficient as in the SSL model. Both analyses show advanced integration of *both* individuals, in the form of triple property features. More complex features decrease predictions of single errors relative to multiple errors, among their included properties. They therefore indicate integration in the representation. The selection of which of these these complex features enter the equation is generally more statistically decisive than the selection of smaller features. It is therefore particularly notable that in these modes, the *introducer* is integrated with these large features. This contrasts both with the SSL model and with the mode group 2 models which are like the SSL model in this respect. In the present case there does seem to be some degree of centralisation of the representations on the introducer dimension, and large features appear on both individuals rather than just on the first.

In mode group 2, all four match features get into both analyses, whereas NMAT gets into neither. In this group of modes, there are differences between the S- and R-orientation analyses. In the S-orientation analysis, only individual 2 has a triple-property feature, whereas in R-orientation analysis, only the first recalled individual has one. Integration is, therefore, concentrated on *first* recalled individuals which were introduced *second.* As mentioned above, the triple features, like those in the SSL model, integrate the *non-introducing* dimensions. In S-orientation analysis, the data show that it is the second introduced individual, the one most is learnt about earliest, which is highly integrated. In the R-orientation, this organisation is obscured. The fragmentation of the second recalled individual strongly reflects the effect of interference in memory due to the retrieval of first recalled individual. Mode group 2 models are more like the SSL models than are mode group 1 models save the expected exception that presentation order effects are reversed.

We interpret the changes in character between the SSL model and that for mode group 1 as the result of the more complex task set by the present experiment. In a majority of modes subjects have to cope with unpredictable shifts in referential focus during the processing of incoming information. Changes instituted to cope with these shifts have effects in cases in which shifts do not happen. These changes led to greater integration of the second individual in mode group 1 than observed by SSL, and a greater centralisation of representations on the introducer. However, except for the fact that it is the *second* introduced individual which is the most integrated in the representation, the subjects' performance in mode group 2 closely resembles the SSL data.

These results show that the same type of model can give a comparable account of the new data as the SSL model gave of the old data. The representation structures implicit in these statistical models solve the binding problem by their mixture of direct and indirect means. In this data, there are small effects of the order of presentation and large effects of order of recall on the pattern of errors across the pair of individuals. The effects of recall order are consistent with those observed by SSL, and here, because order of recall was cued, we can interpret them as due to interference with the memory for the second recalled individual by the act of recalling the first recalled individual. These asymmetrical effects in mode group 2 are therefore to be explained by a retrieval process operating on the representation rather than by asymmetries in the representation itself.

The effects of order of introduction are new to this experiment. The SSL data was consistent with an interpretation based on a strategy of choosing to recall first what is best known which was often the first presented individual. In mode group 1, cueing exposes the difference in accuracy between individuals in the S-orientation analysis as being related to introduction order. This difference in mode group 1 is due to some asymmetry in the representation of individuals.

In mode group 2, there is still evidence of recall interference but also evidence of order effects based on something other than primacy of introduction; the second introduced individual is equally well or better remembered. These are modes in which readers learn much about the second individual introduced early in the texts. If we make a distinction between a *primary* individual on which processing focuses, and a *secondary* individual whose encoding is in some yet to be determined sense subsidiary, then the data from the two mode groups can be consistently interpreted. The details of the difference in *effects* on representation of being treated as primary or secondary individual have already been presented in Chapter 3. As we then stated, the criterion for assigning primary/secondary status to individuals is determined by the sequence of presentation of their properties. We assume that the first individual introduced is treated as primary, until it emerges that more information is available earlier about the other individual, at which point assignment is switched.

An interesting detail emerges with regard to NMAT. This feature gets into the model for mode group 1 R-orientation analysis and nearly gets into the S-orientation analysis model for this group ($p = 0.08$). In the R-orientation model which is directly comparable to the model in the earlier study, NMAT has a similar coefficient to the one it had in that model. It does not show any signs of reaching significance in either mode group 2 analysis. The mode group 2 modes disrupt processing of the higher level matchtype structure. Since this processing is not disrupted in mode group 1, the disruption is a result of something other than unpredictable referential switching *per se*. We propose that it is due to the reader transferring their assignment of primary individual from the first introduced to the second.

In Chapter 2 we suggested that the variable, LOCALMIS, in the SSL reading time model represented processes of encoding higher level matchtype structure, and that its absence from our reading time model was a result of disruptions to these processes by unpredictable referential switching. NMAT is one representation of just such a higher level matchtype structure. The distinctions between primary and secondary individuals, and between mode groups determined by the assignment of primary/secondary status, suggests the possibility that the encoding of matchtype structure may be disrupted only in mode group 2. It may be the that the disruption is caused by a change in assignment of primary/secondary status during reading rather than an unpredicatable switch in reference. If this is the case, and LOCALMIS does reflect processing of matchtype information, reading time analysis of mode group 1 should show LOCALMIS reappearing in the regression equation.

This prediction was tested by deriving separate reading time models of each mode group. In mode group 1, LOCALMIS entered the equation with a coefficient of 0.22 seconds, $p < 0.001$ (close to the figure of 0.19 seconds in the SSL model), and, in mode group 2, LOCALMIS entered the regression equation with a *negative* coefficient of -0.21 seconds, $p < 0.0001$. This bears out the interpretation based on the assumption that LOCALMIS represents processing of the higher level matchtype structure, but also suggests that there is something more than a discrete modular process involved in the construction of representations of solutions to the binding problem. Readers actually accelerate when encountering a mismatch when processing texts presented in mode group 2. This acceleration on detection of a mismatch is accompanied by greater coefficients at all levels of MISLOAD, reflecting a trade off between once-and-for-all processing on detection and recurrent processing repeated on each subsequent reference.

Before proceeding to the next part of the recall error analysis it is worth pointing out that the difference between reading time models of each mode group are not just confined to processing associated with LOCALMIS. In Chapter 3 we presented details of differences in terms of articulatory rehearsal processes which revealed further complexities into the processing involved in the construction of representations of texts presented in different modes.

8. Development of radically indirect models

In this section we describe the development of indirect models. It begins with a brief outline of the independent features, which are contrasted with features used in the development of direct models. As we have already given detailed consideration to similarities and differences between direct and indirect approaches to modelling underlying representation structures reflected by error patterns, details about the development of the indirect models will be kept to a minimum. This will be followed by the presentation of indirect models based on observed data of each mode group, and a detailed discussion of the findings.

8.1. Candidate features for indirect models

The intra-individual features of indirect models are higher order. Instead of being identified by a proposition such as, *The first individual is "red" and "square"*, the feature is identified with the function *an individual's colour and shape* which can takes values such as, "large square", "small square", etc. Since it is the degree of congruity or similarity between stimulus and response which determines the contribution of features to the statistical model, this compression does not alter the logical situation but the model gives a better picture of the underlying integration of the representation structures. Statistically it is equivalent to placing the restriction on regression equations that they either contain variables corresponding to all the object-level features subsumed under a selected higher level feature, with the same coefficient, that is, they are assigned the same degree of saliency, or enter none of them. When we come to construct indirect intra-individual features this restriction has to be given up. However, the loss of legibility is compensated for by a closer relation to implementations of the resulting representations.

The intra-individual features in indirect models are identified by existential propositions of the form: *x(Fx & Gx)* where *F* and *G* represent property attributes, and *and represent their respective contrasted attributes, hence for the colour* dimension, if *F* represents "green", then *represents "red". In the MIT each* text has different property attributes, so these features are still schematic, but within any text, a feature has a determinate content. Thus, features can take the values true or false to denote the congruence, or the lack of it, between the stimulus presented and the response made. For example, one feature was identified by, *There is an individual which is both, "red and square"*.

Each feature identified a variable whose value for a response type was the proportion of times its proposition had the same truth value when applied to both stimulus and response. Thus for a completely correctly recalled text, all features have a value of 1, since anything true of the stimulus is also true of the response, and anything false of the stimulus is false of the response.

The following is a summary of the sorts of features that were included as independent variables in the development of more indirect regression models:

(1) Features integrating attributes of either individual are included. The population of such features generated consisted of the features made up of all consistent subsets of <*A*, ~*A*, *B*, ~*B*, *C*, ~*C*, *D*, ~*D*>, ranging from *A* to *There were eighty such features in all.*

(2) As in the direct model features integrating the property attributes across dimensions, representing matchtype information, are also included. There are four of these, DIMAMAT, DIMBMAT, DIMCMAT and DIMDMAT. Each is identified by a proposition of the form: *xy(Fx & ~Fy)* where *F* is the predicate identifying the relevant dimension.

(3) NMAT is a meta-matching feature. As in the direct model it was defined in terms of the number of matched dimensions in a text.

8.2. Indirect models of representation features and discussion

Apart from the higher number of independent variable (there were 85 feature in total) the regression analysis technique was no different from that for the development of direct models. The dependent variable remains the same as in the direct model and was computed in the same way. Here we present only the R-orientation models for each mode group since they suffice for our purpose of comparing and contrasting their predictions with direct models. Recall error analysis in this orientation reveal the largest asymmetries between pair of individuals, and so are the most difficult for indirect models to account for. They are also better at capturing the structures of representations as other studies have shown (Levy 1989, Levy and Stenning, 1988). The two R-orientation models for mode groups 1 and 2 are shown in Table 11. The goodness-of-fit of the predicted models are illustrated in the Histograms comparing the observed response types with those predicted by the model in Figures 1 and 2.

Figure 1: Observed and predicted response type of mode group 1

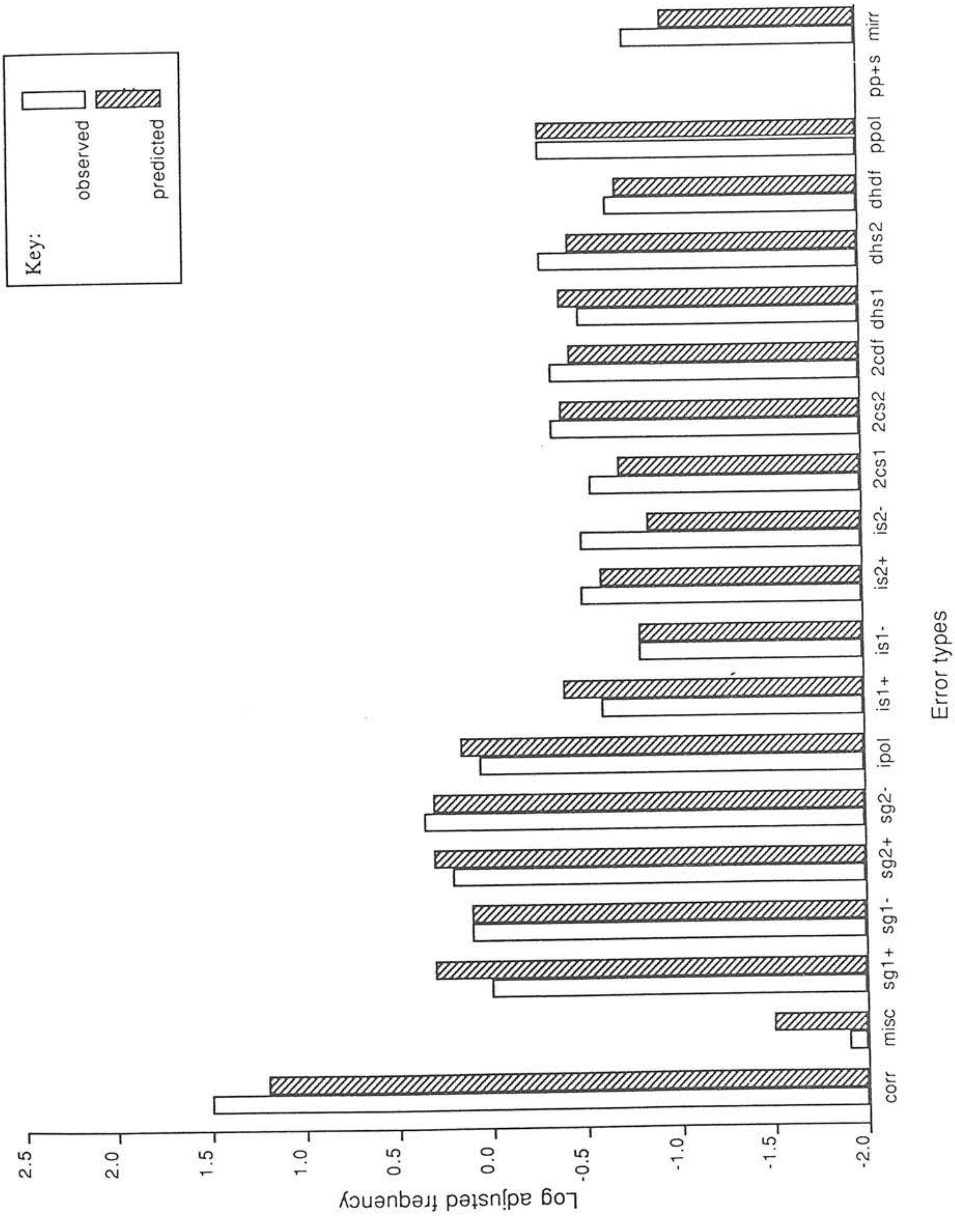

Figure 2: Observed and predicted response type of mode group 2

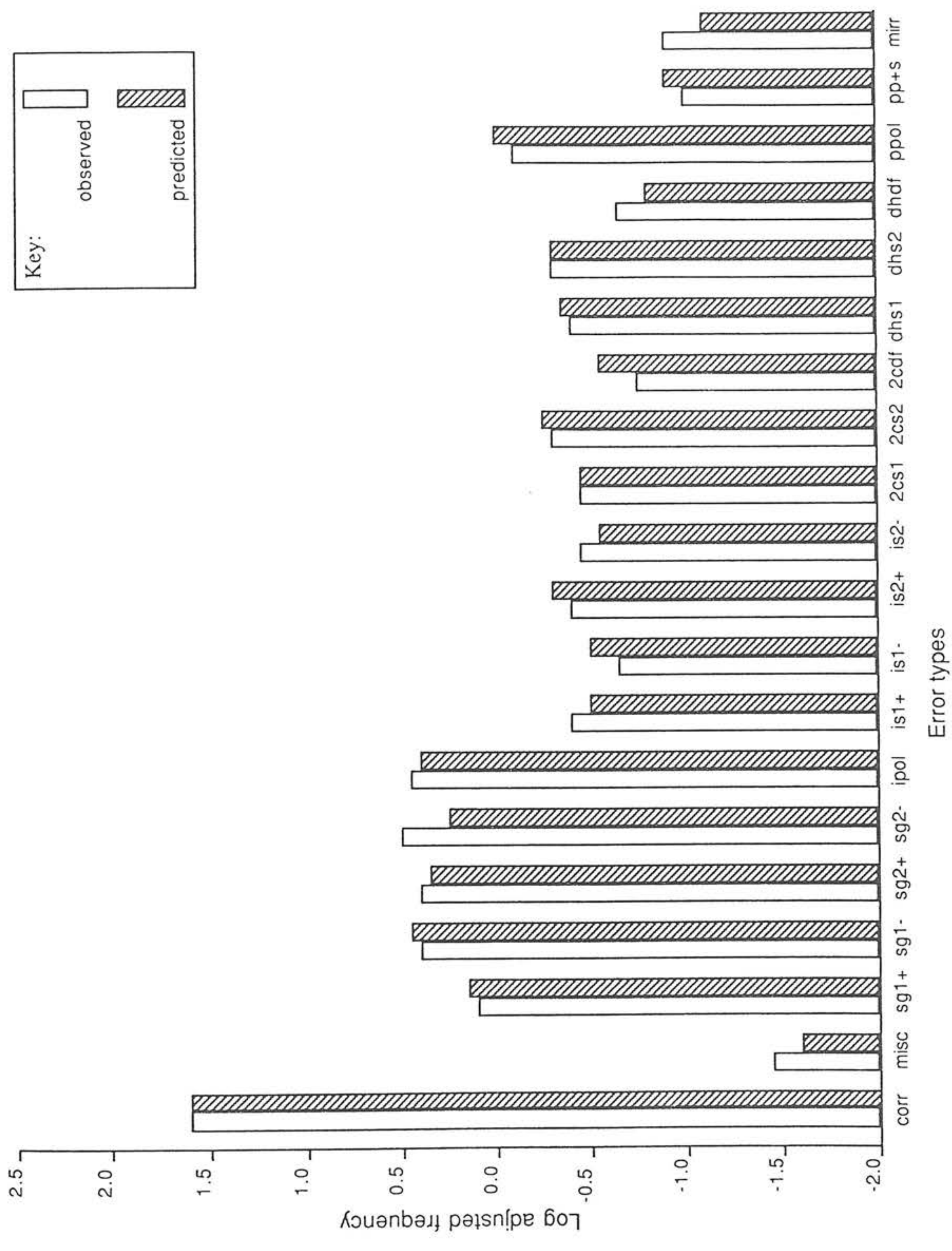

Table 11

Summary of indirect models predicting error frequencies from feature scores

Mode Group 1 $R^2 = 0.82$ df. = 10/73			Mode Group 2 $R^2 = 0.92$ df. = 14/82		
Feature	Coefficient	Standard Error	Feature	Coefficient	Standard Error
Intercept	-3.76		Intercept	-4.91	
DIMAMAT	0.41	0.17	DIMAMAT	0.70	0.10
DIMBMAT	0.49	0.12	DIMBMAT	0.37	0.09
			DIMCMAT	0.51	0.07
DIMDMAT	0.31	0.10	DIMDMAT	0.44	0.07
AD	0.70	0.13	~B	0.74	0.11
A~C	0.48	0.11	~AD	0.21	0.08
B~CD	0.79	0.15	~B~CD	0.46	0.09
			~A~B~D	0.39	0.08
			~A~BC	0.49	0.08
			A~BC~D	0.46	0.10

The indirect models give just as good accounts of the observed error frequency data as their direct counterparts, despite the fact that they cannot account for asymmetries between the two individuals. They compensate for this deficiency by giving improved accounts of the other aspects of the data, among them the ratio of individual polarity to property polarity errors, and the ratio of polarity errors to singletons. The results of cueing recall show that a good proportion of the asymmetries between the first and second recalled individuals are the result of interference at the time of recall, and if the effects of these processes were accounted for, indirect models would give a still better account of the underlying representations.

Indirect models are harder to relate to their predictions. With direct models it is transparent what portion of the structure a feature applies to, but in indirect models this is not so: relations between subsets of the features must be kept in mind when evaluating the models. With direct intra-individual features, larger features increase predictions of multiple errors relative to single errors in an intuitive fashion. That is, large features indicate more cohesive representations of bound attributes, which in turn would make recall errors more interdependent. With indirect features, this simple relationship between size of feature and size of error does not hold since a multiple error may actually preserve the truth value of a feature while a single error would change it. So large features no longer automatically predict more multiple errors, but they do constitute greater integration *in the representations.*

The differences in predicted models of features for each mode group can be interpreted in terms of the effect of order on constructed representations independent of the effect of recall effects on errors. On the bases of differences between the direct models presented here we concluded that in mode group 2 the second presented individual is better remembered than expected, and suggested that this was the result of that individual being treated as the primary one in the representation. To some extent this is borne out by the fact that the indirect model for mode group 2 has more large features than that for mode group 1. This, we take as further evidence for the distinguishing these two concepts of integration; the integration of the *recall,* and the integration of the *representation,* of individuals described in a text.

There is, however, a relationship between the size of features and the complexity of inference required to resolve the properties of the two individuals. At one extreme, in a model containing 16 features corresponding one to each possible type of individual, it would suffice to find the two positive features in a data base to resolve the pair of individuals. At the other extreme, indirect models with only single property intra-individual features, unlike direct models with single properties predicated of constants, could not resolve the individuals at all. This fact brings out the gain in explicitness made by indirect models. Instead of achieving binding through some unknown contextual terms, in this case, the constants of direct models, indirect models contain only textually explicit properties. The direct models in fact show that direct binding through explicit textual features can not account for all the error pattern frequency data.

One striking feature of the indirect model for mode group 2 is that the selected binary features are not always compatible with ternary features The binary feature $B\tilde{}C$ contradicts all four ternary features. This type of organisation has been observed in other data sets, including indirect models fitted to the SSL data, although it does not emerge in the model for mode group 1 presented here. Pairs of contradictory features are important in resolving the inferences from these data bases, since if such a pair are both present, parts of both individuals are thereby specified. Further study of indirect models for other data sets is required to understand the way in which features are organised to facilitate inference.

For what pairs of error types can features be constructed which will differentiate one member from another by predicting different frequencies for them? For what pairs of error types will the differentiation always be in a single direction, and for which could either prediction be found a model within this class? The answers will depend on what class of propositions are admitted as features. To take an example, one may ask whether features of the sort used here can discriminate between double complimentary errors and double homogeneous errors as NMAT (number of matched dimension) does. If we admit complex disjunctive features, we can state NMAT as a disjunction of conjunctions. For example, truth values of 1 for the following disjunctive describes NMAT value for on property dimension denoted by predicate F:

$$xy((Fx \;\&\; Fy) \text{ or } (\tilde{}Fx \;\&\; \tilde{}Fy))$$

But if we limit ourselves to simple existentially quantified conjunctions of properties, the answer is not so obvious. NMAT is offered for inclusion but does not get into the indirect model for mode group 1 (it is nowhere near significance). Has NMAT disappeared from the equation because the equation has some new account, and if so, in what terms is this account couched?

Consider just the two dimensions on which double errors occur, and consider all four possible intra-individual features expressing relations between the predicates of these two dimensions. (To recap, a double complimentary error occurs when an originally matched dimension is recalled as mismatched *and* an originally mismatched dimension is recalled as matched). Hence a double complimentary error changes the truth values of two of these features, whereas a double homogeneous error (which occurs when two matching or mismatching dimensions are recalled as two mismatching or matching dimensions respectively) change either one or three of the features depending on whether the two errors are on the same individual or on different individuals. This predicts that double homogeneous errors on different individuals would be least common of all four categories, and this is observed both in mode group 1 and in the SSL data. But contrary to our observations, it predicts that double homogeneous on same individual should be commoner than double complimentary errors. Further investigation, however, reveals that these classes of error are differentiated by the type of feature they disrupt: double features which contain two positive or two negative predicates are disrupted by all double homogeneous errors. Double features which contain a positive and a negative predicate are disrupted by double homogenous errors on the same individual, and by double complimentary errors of either configuration. The intra-individual features of the indirect model from Mode Group 1 contains seven pairs of predicates that contain both positive and negative predicates, as opposed to four pairs with one positive and one negative predicate. It would seem that it is this distribution which captures the balance between the four categories of double error, thus displacing NMAT from the equation. However, a more appropriately designed study is necessary to enable us to confirm this account.

What interpretation can we place on the contrast between what we have been calling positive and negative predicates? The only importance of the distinction in determining the logic of the features is that the predicates are contradictories (in this context). But to appeal to the distinction in explanations of error frequencies requires a stronger interpretation: the account just given of relative frequencies of double dimension errors requires some principled asymmetry between members of the pairs of vocabulary items which define dimensions. Since the structure of presentation (that is, which member of the lexical pair is attributed to which individual) is randomised, the only way of distinguishing between individuals is based on the absolute relations between the members of the contrasted pairs of words. The nominal cohort has no such structure, but the other three cohorts intuitively have asymmetries within their pairs of words. Sometimes these are asymmetries of markedness (eg, "big/small") or sometimes the basis of the ordering is bit more vague (eg, "wet/dry", or "red/green") but in all cases there is an intuitive natural ordering (Lyons 1977) of the members of the pairs, which we also inadvertently adopted in coding the pairs of words. Although the members of the pairs are assigned randomly to individuals, the pair orderings are preserved in the translation from words to positive and negative predicates in the error analyses. Further investigation of the impact of these asymmetries is required, and one of several issues addressed in the next experimental study presented in Chapters 5 and 6. Only the formulation of explicit models of representation can point up such necessities.

9. Summary of first study results and motivation for the second study

To summarise, the memory error models of the SSL type fit the present data about as well as the SSL model fitted their data, and reveal some differences in the organisation of representations between mode groups. These models are perspicuous summaries of the dependent and independent structures of the representations in long term memory. Their usefulness as descriptive tools is not displaced by a theoretical preference for indirect models. Indirect models are hard to read, but their sufficiency shows that the referential elements of the direct models are unnecessary to explain the variance in the data. In light of this conclusion we develop only indirect models of the structures of representation in the next study reported here. As far as the nature of the structures of representation is concerned the next study is designed to provide further insights into the effect of content on representation structures. In the previous section the relative importance of temporal order of content and content *per se* in representation strategies was briefly discussed. The question being how extensive is the role of general knowledge in the solution to the binding problem, and does temporal facts about the content (that is, the order in which properties of individuals are presented in MIT) have any significant role to play in determining the sorts of representation structures that have been predicted by models developed so far. The next study is designed to address this is issue as directly as possible. In keeping with our motivation for previous experiments the design is not radically different from that of the first study. In order to determine the relative influence of each, the dimensional order of each individual was varied but not the temporal order of presentation of each individual's attribute. This exercise was repeated three time which effectively gives us three different temporal orders (each with three different individual dimensional orders) and as we will see in Chapters 5 and 6 this difference has important consequences on the structure of representational feature predicted by recall models.

The issue about the effect of temporal order of content is closely connected with that of accessibility to information about matchtype structure of MIT texts. Simply expressed, presenting each individual in different dimension orders would make it more difficult to extract information about whether both individuals are matched or mismatched on a particular property dimension. Examples of MIT texts together with a more detailed explanation in the introductory section of next chapter (Chapter 5) will elaborate on this point. The first study was motivated on the grounds that some of findings and conclusions drawn by SSL seemed closely dependent on the predictable nature of MIT texts. To overcome this possible shortcoming texts with a degree of unpredicatability in the referential order of each individual were used in this study, and the results show that the main reading time findings of the SSL study, such as the Semantic Ordinal Effect and the modularity of the cognitive processes involved in the constructions of representations of solution to the binding problem, were *not* an artifact of one particular sort of predicatability in MIT texts. The reading time models further predicted other processing which were shown to be a consequence of text mode and rehearsal strategies. These models served a double purpose.

First, it confirmed our claim that the MIT texts were treated more like natural texts and not at all like disjointed lists of words in working memory. Second, it gave us an added insight in differences between processing devoted to different individuals, and which the structures predicted by the representation models supported.

Overall, therefore we can confidently conclude that the results of the first study replicates much of the basic findings of the SSL study and extends our understanding of the sorts of cognitive processes and representation structures involved in solving the binding problem. However, this conclusion still leaves a number of unanswered questions about the effect of other sorts of predictability in MIT texts which remained largely intact in the experimental design used in this study. The next study is designed to address the effect of predictable nature of matchtype status of property dimensions on representation strategies employed to solve the binding problem. It is clear from the results of the first study that matchtype information is an important predictor of both reading times and recall error patterns. This raises the obvious question about the extent to which construction processes are directly dependent on the ease of availability of this sort of higher level semantic information. Though presenting texts in different modes did disrupt accessibility to matchtype information (and we have noted the consequences of it on predictions of the reading time model), the essential predictability due to the identical dimensional order of both individuals remained intact. For example, in texts in forward format the colour dimension of *both* individuals *always* preceded the texture dimension though the exact temporal position obviously varied in different modes. In the next experiment, therefore, individuals will not necessarily be described in identical dimensional order; each will have different dimensional orders. So it will be possible for readers, at say the fourth sentence, to simultaneously know about the colour attribute of one individual and the texture attribute of the other individual. This means that information about matching status will not be presented in a simple consistent temporal order.

The other question that these findings raise is a more theoretical one. On the bases of the models presented hitherto we make a number of claims about construction processes and more particularly about the structure of representations which are independent of the effect of content on the modelled cognitive processes. In Chapter 1 we defended this approach on the grounds that though a complete solution to a the binding problem is a function of higher level semantic structure, as well as content of texts, it is nevertheless possible to study the processes related to the former independent of those affected by the latter. This dichotomous approach was further justified on the grounds that the highly constrained nature of the texts employed in MIT enabled us to make this theoretical distinction. The next experimental study is designed to provide further support for these theoretical assumptions, and extend our understanding of the numerous effects of information about semantic structures on the construction processes and the representation of a solution to the binding problem.

Finally, the present study has highlighted the influence of rehearsal strategies on reading times. Part of the time spent on syllabic rehearsal was shown to be determined by the primary/secondary status of the individual. However, the extent to which reading time due to rehearsal were determined by this was unclear since we did not control for syllabic length of vocabulary items randomly selected to describe each individual. In order to clarify this issue, in the next experiment the syllabic length of the vocabulary was strictly controlled. As it turned out this was not very helpful since reading time due to rehearsal was evenly distributed across each sentence and therefore not easily available for developing rehearsal models of reading time. We will return to this issue in the final Chapter of this thesis.

Chapter 5

1. Introduction

In this Chapter we report the analysis of reading times results of the second experiment. This experiment was designed to extend our understanding of the processes involved in the representation of the structures recruited in the solution of the binding problem in human memory. From the previous study it is clear that the constructive processes and the encoded structures or associations between attributes are determined by two distinct aspects of MIT texts; dimension order and matchtype structure. As discussed in Chapter 1, more general issues about the role of content and relevant general knowledge recruited in the solution of the attribute binding problem will not be investigated in this study, which is designed to address two specific aspects about the effect of content at higher level, in particular its effect on the sorts of semantic structures which as has been shown play a major role in the construction of representation of individuals.[6]

First, what effect, if any, does the temporal position of a particular property dimension have on processing loads during construction of representations. The use of two different formats, *forward* and *backward*, in the previous study was one attempt at answering this question. The present study is specifically designed to explores aspects of this issue not addressed by the previous study. On the bases of previous results it is predicted that temporal, or sentence, position of property dimensions will not have a significant effect on the sorts of features that are encoded in representations.

This experiment was also designed to investigate the effect of similarity in the order in which both individuals are described in an MIT text. In all previous studies (eg, Stenning Shepherd and Levy, 1988; Stenning, Patel and Levy 1987) the temporal order of both

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[6] The definition of content for the purposes of this study is highly constrained. It refers to the property dimension of a lexical item, and therefore extends only to the literal meaning of the actual words used to describe a particular individual. This is justified on the grounds that such higher level aspects of content play a pivotal role in determining the notion of semantic structures, such as matching status, recruited to solve the binding problem.

individuals was the same. For example, the colour of both individuals always preceded the texture. Little reflection is needed to realise that this type of predictability in the MIT facilitates the encoding of information about matchtype structure. In other words, the similarity in temporal order enables readers to encoded inter-individuals associations in a representation with relative ease. The results of the previous study show that though unpredictable referential switches affected processing loads and the organisation of the representation, matchtype information played a significant role in the solution to the binding problem. The major aim of this study is to investigate the effect of dissimilar property dimension ordering on construction processes and representation structures.

2. Dimension order and the Semantic Ordinal Effect

In the SSL study the dimension order or, 'format', as it will be referred to was invariant in all texts, and therefore, highly predictable. To check whether this had a significant effect on the Semantic Ordinal Effect texts in the last study were presented in two different formats, *backward* and *forward.* It was shown that apart from the slower pace at which texts in backward format were read, this had no significant effect on the Semantic Ordinal Effect. The order in which dimensions are presented is not a major determiner of the processing loads and the structure of representation in working memory. However, the first study was a limited attempt to explain the effect of dimension order on the Semantic Ordinal Effect. Text formats remained largely predictable because apart from one major differences in dimension orders both formats shared a number of regular features. Such similarities may have had the effect of concealing any differences due to different property dimension presented in the same temporal position. In order to see if this was indeed the case the number of formats used in the present study was increased to nine.

Below we give examples of two such stimuli texts which have the same higher level semantic structure, that is matchtype, but different dimension orders for each individual.

Format 1 (matchtype +--)	Format 5 (matchtype +--)
There is a chef	There is a chef
There is a vet	There is a vet
The chef is Swiss	The chef is tall
The vet is Swiss	The vet is tall
The chef is tall	The chef is mad
The vet is short	The vet is sane
The chef is mad	The chef is Swiss
The vet is sane	The vet is Welsh

All texts used in this study were in Predicate by Predicate (P x P) mode, and the first two sentences always referred to the profession of each individual. These texts have the effect of rendering the property dimension order between different texts largely unpredictable. Presenting such a relatively large number of different text formats in a random order greatly reduced subjects' perception of format regularities displayed by texts in the first study. This provided further information on the extent to which the Semantic Ordinal Effect was due to regularities in the presentation order of property dimensions. Evidence so far, suggests that such an effect is small though its significance remains unclear. The present study was designed to clarify the effect of fixed dimension order on working memory processes, represented by the Semantic Ordinal Effect, and on long term representation structures. We will return to the latter in the next section and Chapter 6.

If reading times of the above example texts are not significantly different then that would provide some very clear support for the distinction made between content and form outlined in Chapter 1, and provide further justification for our methodological approach, which concentrates on the effect of higher level semantic structures on the representation of solutions to the binding problem. Finally, such a result would confirm the usefulness of processing and representation models in increasing our understanding of the role of higher level semantics in knowledge representation during text comprehension.

2.1. Matchtype structure information and the Semantic Ordinal Effect

We have seen that the Semantic Ordinal Effect can be factored out into a number of construction processing loads. Some of these processes (eg, MISLOAD) were defined in terms of information about semantic structures dependent on whether properties describing individuals were the same (matched) or different (mismatched). In Chapter 2 it was argued that matchtype information is recruited to construct associations between properties of individuals. Hence, the Semantic Ordinal Effect is partly explained in terms of loads imposed by the construction of increasingly elaborate representation structures which capture some or all of the information conveyed by the matchtype structure of a typical MIT text. At the very outset we mentioned the alternative possibility of conceptualising the Semantic Ordinal Effect as a consequence of a simple increase in the number of known properties of individuals. Though this is too simplistic an explanation for the observed sentence reading time, it does not have to appeal to higher level semantic information such as matchtype structure. In previous studies, the text format made it difficult to distinguish between the separate contributions of matchtype information and that due to an increase in the number of properties to the Semantic Ordinal Effect. This study is designed to enable us to consider this issue as far as it is possible to do so within the constraints of texts in MIT. The limits to which the separate effects of each sort of processing to reading times can be analysed will become clearer once the experimental design has been described in the appropriate section below.

In itself the correlation between learning more about individuals and gaining more information about the matchtype structure is not a problem. Independent of the extent to which readers use higher level information as part of their representation strategy, the most significant finding is that the Semantic Ordinal Effect reflects the increasing complexity of representation structures necessary for the solution of the binding problem in the MIT. In the SSL study information about matchtype structure was highly accessible because of highly predictable referential switches, *and* a fixed property dimension order for both individuals. The following example text in P x P mode illustrates the point that identical dimension order in which is individual is presented facilitates perception of matching status:

Format 1 (matchtype -+-)

There is a chef
There is a vet (-)
The chef is Swiss
The vet is Welsh (-)
The chef is short
The vet is short (+)
The chef is sane
The vet is mad (-)

In this experiment all texts were presented in the P x P mode but the property dimension order of each individual in a text was not necessarily the same. which effectively enables us to investigates the effect of disrupting another sort of predictability present in texts used in previous experiments. As we have noted, conceptualising the properties describing individuals on one particular dimension in terms of matches and mismatches is a consequence of the organisation of the vocabulary which supports the rich general knowledge that reader bring to bear upon the solution to the binding problem in MIT. Hence, the application of the notion of matchtype structure is limited to typical MIT texts. Though this makes it a special case, the notion of higher level information is nevertheless generalisable to representations of less constrained texts (see for example, Bruner 1986). Any solution to the binding problem would require some sort of relational structure which captures the associations between properties belonging to one individual. We make the assumption that wherever possible readers would utilise such higher level information as part of their representation strategy during comprehension. As well as our own findings, a study by Morris, Bransford and Franks (1977) supports such an assumption. They report that where appropriate subjects are likely to extract the implicit relational information and encode it in the representation. In their case the relational information was determined by retrieval cues. They found that subjects encode the relational structures appropriate for subsequent error free retrieval of descriptions presented in texts.

In the case of MIT texts, information about matchtype structure plays a similar role. As we have seen it influences the manner in which associations are recruited to bind properties with inter- and intra-individual links to resolve reference. Here we intend to investigate the effect on subjects' representation strategies when matchtype information is not so readily perspicuous or available. For example, given the following text, which has the same matchtype at the one above but presented towards the latter part of the text, what effect does it have on subjects representation strategy:

Format 3 (matchtype -+-)

There is a chef
There is a vet (-)
The chef is Swiss
The vet is mad
The chef is short
The vet is Welsh (-)
The chef is mad (+)
The vet is tall (-)

At sentence 8 of both example texts the reader has the same information about matchtype structure; it is only the sentence position where it become available that varies, in that, apart from the first mismatch, the same information available at fourth sentence in the first example (format 1) is not available till the sixth sentence in this text (format 3). As we will see this makes a major difference to readers strategy for constructing a representation of a solution to the binding problems. In Chapter 6 we present results which show how such differences in strategy are reflected in differences in errors patterns of texts presented in different formats. More specifically, we show how subjects seem to recruit different sorts of intra-individual associations when format affects the availability of matchtype information during the early parts of texts.

Finally, though for our purposes we assume that higher level semantic structures, such as matchtype, is largely independent of content, this is clearly unlikely to be the case. Such information is a direct outcome of the general knowledge that a reader brings to bear on a text comprehension task, and, one that is ultimately dependent on her perception of the content of texts, which in this case is the property attributes of individuals. However, the studies presented here concentrate on semantic structures because these are not usually (Iser, 1976) given but inferred which, as we have seen, can reveal a lot about the general nature of working memory and representations in long term memory. Similar sorts of general inferences includes the notion of markedness where the order in which individuals attributes are presented has an effect on text comprehension (Lyons 1977), and syntactic constructions, which can effect things such as topicalisation (Chafe 1976), both of which we touched upon in Chapter 1. The success or the efficiency of the inference process is determined by general knowledge, and appropriate partial representations of either foregoing parts of the discourse or other directly relevant contextual information. Accordingly, matchtype information is that part of the semantic structure of texts which facilitates a knowledge rich solution to the binding problem.

2.2. Format group and matchtype

If the differences in dimension order is disregarded, the nine formats can be collapsed into three groups which reflect the order and availability of matchtype information independent of content. These three groups will be referred to as 'format group'. An example of each format group is given below:

Format Group 1 (+--)	Format Group 2 (+--)	Format Group 3 (+--)
There is a chef	There is a chef	There is a chef
There is a vet (-)	There is a vet (-)	There is a vet (-)
The chef is Swiss	The chef is Swiss	The chef is Swiss
The vet is Swiss (+)	The vet is tall	The vet is sane
The chef is sane	The chef is tall (+)	The chef is tall
The vet is mad (-)	The vet is sane	The vet is Swiss (+)
The chef is tall	The chef is mad (-)	The chef is mad (-)
The vet is short (-)	The vet is Welsh (-)	The vet is short (-)

The resolution of matching status of each dimension is indicated ('+' or '-') at relevant sentences. It is evident that differences in dimension order of individuals affect the availability of matchtype information, which allows to analyse the observed data purely in terms of the effect of matchtype structure on text comprehension in MIT. Format group 1 is similar to a normal P x P text with identical dimension order for both individuals; matching status of dimensions is therefore resolved at every alternate sentences. This is not the case for texts in format groups 2 and 3. Texts in format group 3 have the most disruptive effect on the availability of matchtype information. The delay in information about matchtype structures in format groups 2 and 3 results in higher sentence reading times.

We have already noted that in MIT the phenomenon of lower reading times for matched attributes is most salient in P x P text mode, and suggest that this is an outcome of a particular combination of predictable mode and format. Thus, is would follow that the *temporal order* in which information about matching status of dimension is presented should have a significant effect processing and readers' representation strategies. Observed reading time data reveal such effects on processing loads associated with matched attributes. Where matching status information is lacking, and therefore, accompanied by other unresolved attributes of either individual, as in format group 3 texts, reading times are particularly high, and even exceed those of mismatched attributes. Possible reasons for this observation will be considered in the next section, and accounted for by a reading time regression model. It is mentioned in this section to illustrate the potential of a highly constrained research approach (MIT), and methodology, in broadening our understanding of cognitive processes underlying the simplest kind of text comprehension.

2.3. Effect of matched attributes on construction processes

In Chapter 2 we touched upon the effect of matches attributes on reading times. In the SSL experiment learning about matched attributes typically required less reading time. It was suggested that this was due to subjects' reliance on redundant information about the occurrence of a particular lexical item which described both individuals. A similar but a more frequent effect was observed in the first experimental study. The exclusion of MATLOAD from Model 1 reflected the relatively small processing load this incurred compared to those associated with MISLOAD, NEUTLOAD and loads due to referential unpredictability. Matched attributes therefore do not seem to be encoded in terms of more elaborate representational structures.

Our findings and explanation for them do not concur with that of other related research on such similarities in working memory. Associative list learning studies showed evidence for both retroactive and proactive interference during learning and retrieval (see for example, Keppel and Underwood 1962; Wickens, Born and Aller 1963, Kincaid and Wickens 1970, all three reported in Wickelgren 1977), Conrad (1964), Wickelgren (1966) and Lowe (1989) also report confusion due to phonemic similarities, and more recently, related studies such as, Frick (1988) and Yuill, Oakhill and Perkins (1989) report effects of limits in working memory on language comprehension. Similar interference during retrieval of previously learnt sentences which shared semantic similarity about a location or a person are reported by Anderson (1983). Wickelgren (1965, 1966) showed that phonemic similarity led to interference in working memory. The reason why a similar increase in cognitive processing load, or indeed, any significant problems during retrieval, due to matched attributes have not been observed in our studies, is that, unlike simple lists of associated pairs of words, our texts have a higher level semantic (relational) structure which supports knowledge rich representation structures. Readers employ this information as part of their representation of a solution to the binding problem and thus, overcome the potential confusion over phonemic or semantic similarities of matched attributes. Anderson's (1983) results can therefore be explained by the fact that there are no obvious similar cases of higher level information that could be advantageously encoded in the representation to avoid interference during subsequent retrieval.

What would happen if the format of text made it relatively difficult for the reader to perceive and bind attributes belonging to each individual with the help of higher level semantic information? On the bases of the above, we would predict that in the absence of matchtype information, together with the added complication of different dimension orders for each individual, (these two are mutually determined as a closer examination of the example text in format 3 in the previous section will reveal) the processing loads associated with matched attributes would increase. This should happen for two reasons that are direct consequences of all relevant studies mentioned so far. First, reading times would increase because matchtype information in no longer as readily available as in invariant format texts, which is particularly the case in the early part of texts. Second, if not presenting a pair of matched attributes in consecutive sentences does increase the potential for interference, then readers would be expected to spend more time processing matched attributes. This makes sense since information about other unresolved attributes of each individual opens up the possibility of solving the binding problem by constructing alternative more elaborate, and therefore, more time consuming associations between attributes. Our findings lend support to both these possibilities and analyses of recall error results presented in Chapter 6 confirm these accounts for increases in reading times of matched attributes.

2.4. Effect of format on rehearsal

In the first study we presented a model of reading times which factored out the contribution of syllabic rehearsal to the Semantic Ordinal Effect. The contribution of rehearsal to processing loads was determined by the semantic and representational status of individuals; that is, the designation of an individual as primary or secondary, and whether it was currently referenced or not affected the amount of reading time devoted to rehearsal. In the first study, text modes designed to maximise unpredictable switches in reference enabled us to investigate the role of Articulatory Rehearsal Loop and its counterpart Articulatory/Acoustic Loop (ARL/AAS) in working memory. Reading times of texts with more predictable switches between referents, such as in P x P mode, do not show any discernible contribution of rehearsal (Stenning, Shepherd and Levy, 1988). This is because rehearsal load in texts with predictable switches in reference is markedly reduced, and further the effect is more evenly distributed across sentences.

For these reasons we did not expect to observe any significant contribution of syllabic rehearsal to reading times in the present study. Nevertheless, the syllabic length and frequency of the vocabulary used to generate stimuli texts were strictly controlled. The vocabulary set of each dimension had an equal number of contrasted pairs of monosyllabic and bi-syllabic words. Although all texts were presented in P x P mode, some formats may have a significant effect of processing devoted to syllabic rehearsal. This is particularly likely to be the case with properties that are unresolved in terms of matching status, which, as described above, is a notable consequence of presenting each individual's attributes dimensions in different orders. Such an observation would indicate that syllabic rehearsal is not always organised around attributes of a single individual. Our previous account of the role of semantics in determining certain aspects of rehearsal would have to be extended to explain the effect learning about properties belonging to more than one individual. However, results of the present study show that format (group) does not have a significant effect on rehearsal processes, which provides further support for our initial conclusion that the main determinant of rehearsal processing loads is not a simple additive effect of more information, but an effect of bounded attributes of each individual. Of course, rehearsal must have taken place during the present task but the lack of any significant observable effect due to syllabic length of attributes describing individuals supports the view that rehearsal processes are sensitive to the referents of attributes independent of the format or its effect on accessibility to matchtype information.

Next we will describe the full design of the experiment. This should clarify some of the details about the two levels of differences in format and format groups, and their effect on availability of matchtype information.

3. Method

3.1. Design

Texts are read by subjects one sentence at a time in a self-paced reading time task. Each text consisted of eight simple declarative sentences describing two individuals in terms of their profession, nationality, stature and temperament (not necessarily in that order).

There are 576 possible formats in which texts describing two individuals on four dimension can be presented. In the previous study texts were presented in two formats, *forward* and *backward*. Assuming that the individuals are always introduced in one dimension which therefore has to be always mismatched the possible number of formats is reduced to 36. In this study, as all texts were introduced in Predicate by Predicate (P x P) mode, the first two sentences introduced to each individual in terms of their profession. Out of the possible 36 formats, 9 were selected according to the criterion that apart from the introducer the other three dimensions should occur at all possible temporal positions for each individual. It is obvious that more than one possible subset of formats would satisfy this criterion. Hence, out of the six possible dimension orders for the first individual one set of three was selected to ensure that one format was identical to the original P x P texts used in previous studies. The dimension orders of the second individual were selected in a similar manner. This gives us the following 9 formats:

Individual-1	Sentence	1	3	5	7
Individual-2	Sentence	2	4	6	8
Format 1		PROFESSION	NATIONALITY	STATURE	TEMPERAMENT
		PROFESSION	NATIONALITY	STATURE	TEMPERAMENT
Format 2		PROFESSION	NATIONALITY	STATURE	TEMPERAMENT
		PROFESSION	STATURE	TEMPERAMENT	NATIONALITY
Format 3		PROFESSION	NATIONALITY	STATURE	TEMPERAMENT
		PROFESSION	TEMPERAMENT	NATIONALITY	STATURE
Format 4		PROFESSION	STATURE	TEMPERAMENT	NATIONALITY
		PROFESSION	NATIONALITY	STATURE	TEMPERAMENT
Format 5		PROFESSION	STATURE	TEMPERAMENT	NATIONALITY
		PROFESSION	STATURE	TEMPERAMENT	NATIONALITY
Format 6		PROFESSION	STATURE	TEMPERAMENT	NATIONALITY
		PROFESSION	TEMPERAMENT	NATIONALITY	STATURE
Format 7		PROFESSION	TEMPERAMENT	NATIONALITY	STATURE
		PROFESSION	NATIONALITY	STATURE	TEMPERAMENT
Format 8		PROFESSION	TEMPERAMENT	NATIONALITY	STATURE
		PROFESSION	STATURE	TEMPERAMENT	NATIONALITY
Format 9		PROFESSION	TEMPERAMENT	NATIONALITY	STATURE
		PROFESSION	TEMPERAMENT	NATIONALITY	STATURE

All texts were presented in P x P mode. Format 1 is identical to P x P mode in previous experiments; both individuals are described in the same dimension order. In this sense formats 5 and 9 are similar to format 1, though within each format the dimension order is different. The higher level similarity reflects similarity about the order in which information about matching status of dimensions becomes available to readers. In order to distinguish such shared properties between formats they will be collectively referred to as *format group 1*. Formats 2, 6 and 7, and, 3, 4 and 8 also share similar semantic structures due to identical temporal orders which determine the availability of matchtype information. These will be, therefore, collectively referred to as *format group 2* and *format group 3* respectively. This similarity allows us to distinguish between the respective effects due to higher level temporal or sentence order, and, dimension order on reading times. The former also determines the order in which matchtype information becomes available to a reader.

Apart from the introducer (profession), individuals were matched on 0, 1, 2, or 3 predicates equally often. As in the previous experiment there are eight different matchtype patterns given that the introducer is always mismatched. These are identified by eight iconic patterns: +++, ++-, +-+, +--, -++, -+-, --+,and ---, where matched and mismatched attributes on a dimension are denoted by plus (+) and minus (-) signs respectively. Since dimension order for each individual was not always similar, in this experiment matchtype of each text was defined in terms of the order in which this information became available to readers. Texts in each format (9) were presented in all matchtype structures (8) equally often; seventy-two (9 x 8) texts made up one complete experimental design.

Below we give three examples of texts in formats 1, 2 and 3 respectively. Examples of texts in all nine formats are given in the Appendix E. Each has identical matchtype structure; the property attribute on the second dimension is mismatched, and those on the third and and fourth are matched (that is, matchtype 5, -++):

Format 1 (-++)	Format 2 (-++)	Format 3 (-++)
There is a chef	There is a chef	There is a chef
There is a vet	There is a vet	There is a vet
The chef is Swiss	The chef is Swiss	The chef is Swiss
The vet is Welsh (-)	The vet is tall	The vet is sane
The chef is tall	The chef is short (-)	The chef is tall
The vet is tall (+)	The vet is sane	The vet is Welsh (-)
The chef is sane	The chef is sane (+)	The chef is sane (+)
The vet is sane (+)	The vet is Swiss (+)	The vet is tall (+)

The important thing to note is that the matchtype information is the same in each example text. However, format effects the temporal order in which matchtype information becomes available. The occurrence of '-' or '+' next to sentences where matching status information becomes available shows how in format 2 and 3 differences in individual dimension orders affects access to it. For example, nationality of the first individual can be followed by the nationality of the second individual either immediately or after one or two other dimensions or after none, two or four sentences. The difference in dimension/sentence 'distance' within formats is one way of describing the effect of differences in dimension order on resolution of matching status of attributes on a dimension.

Texts were presented in a random order. The full design consisted of the following factors (and levels):

1) Format (9 levels)
2) Individual (2)
3) Predicate (4)
3) Matchtype(8)

All factors are within subject factors and fully crossed.

3.2. Vocabulary

The vocabulary set contains 48 words; there were equal numbers of mono- and bisyllabic words. The set is divided into four cohorts of 12 words each corresponding to profession, nationality, stature and temperament (the last two cohorts are very loosely defined) dimensions. Each cohort contains six pairs of antonymous or contrasted nouns or adjectives (see Table 1). Each individual is described by four attributes, one from each pair of property attributes from each cohort. Attributes describing individuals were assigned randomly by a PROLOG text generating program. Vocabulary items were matched in terms of frequency and syllabic length (Francis and Kucera, 1982).

Table 1

Individual Vocabulary Set

Cohort 1	Cohort 2	Cohort 3	Cohort 4
nurse/priest	French/Greek	young/old	tall/short
judge/monk	Welsh/Swiss	fat/thin	strong/weak
vet/chef	Dutch/Czech	rich/poor	sane/mad
doctor/vicar	German/Spanish	clever/stupid	friendly/hostile
teacher/bishop	Chinese/Polish	hungry/thirsty	happy/gloomy
dentist/baker	Swedish/Russian	greedy/clumsy	daring/timid

3.3. Subjects

Twenty postgraduate student subjects were paid five pounds for taking part in the experiment.

3.4. Procedure

Subjects were presented stimuli texts on a BBC model B microcomputer network. Each subject completed two experimental designs. 144 texts were presented in 8 sessions each with 18 randomly assigned texts from the total number.

Subjects were provided with written instructions (see Appendix F), supplemented by detailed verbal instructions during the trial session. It was emphasised that subjects should take as much time to read each sentence as was felt necessary to recall accurately. They were allowed to take breaks of any length of time between sessions. On average the majority completed all the sessions over two or three sittings.

To begin a session subjects logged onto the BBC computer, and pressed the space bar for the first sentence of the text. Reading of the text was self-paced, with the subject pressing the space bar, which was a timed response key, to obtain the next sentence which replaced the current one. Sentence reading times were measured in centiseconds. At any particular time subjects could only see one sentence of the text. At the end of each text, following a warning message, the subject was required to answer a simple question such as "Was there a swiss chef?". The response to the question was followed by the recall stage. At this stage subjects were presented with a menu of four pairs of words which had been used to describe the individuals in the text. Subjects were asked to recall one individual followed by the other. They were not cued to recall individuals in any particular order, neither did they have to recall properties describing each individual in any particular order. Results of the menu aided recall are reported and discussed in the following chapter. Subjects were provided with no feedback on recall accuracy. Subjects pressed the RETURN key to begin the next text presentation.

4. Reading time results

An analysis of variance was carried out, with subjects as the random factor, and format (9 levels), matchtype (8 levels), individual (2 levels) and predicate (4 levels) as fixed factors. All reading time means are given in seconds unless otherwise indicated.

There is a main effect of format (F (8,144) = 18.3, $p < 0.0001$). Texts in format 5 had the fasted mean sentence reading times (1.74 seconds) followed by formats 9, 1, 7, 6, 2, 4, 8 and 3 (see Table 2). The Semantic Ordinal Effect is replicated for both individuals' reading times collapsed across format (see Figure 2, graph E). Mean reading times of predicates of each individual in each format are illustrated in Figures 1 (graphs A-H) and 2 (graph A).

Table 2

Mean reading times as a function of individual, predicate and text format

	Individual 1				Individual 2				All Predicates
Predicate	1	2	3	4	1	2	3	4	
Format: 1	1.23	1.72	1.92	1.89	1.36	1.67	1.95	2.36	1.76
2	1.27	1.73	2.25	2.55	1.37	2.01	2.55	2.70	2.05
3	1.27	1.80	2.42	2.93	1.40	2.09	3.00	2.60	2.19
4	1.25	1.70	2.27	2.77	1.38	2.18	2.78	2.72	2.13
5	1.30	1.73	1.71	1.88	1.50	1.59	1.95	2.23	1.74
6	1.23	1.58	2.26	2.44	1.38	1.99	2.63	2.75	2.03
7	1.18	1.70	2.22	2.50	1.27	2.14	2.44	2.67	2.02
8	1.25	1.76	2.30	2.78	1.45	2.10	2.93	2.56	2.14
9	1.25	1.65	1.70	1.99	1.46	1.16	2.04	2.34	1.76
All Formats	1.25	1.71	2.12	2.44	1.40	1.93	2.46	2.55	-

Figure 1: Mean reading times of predicates by individuals

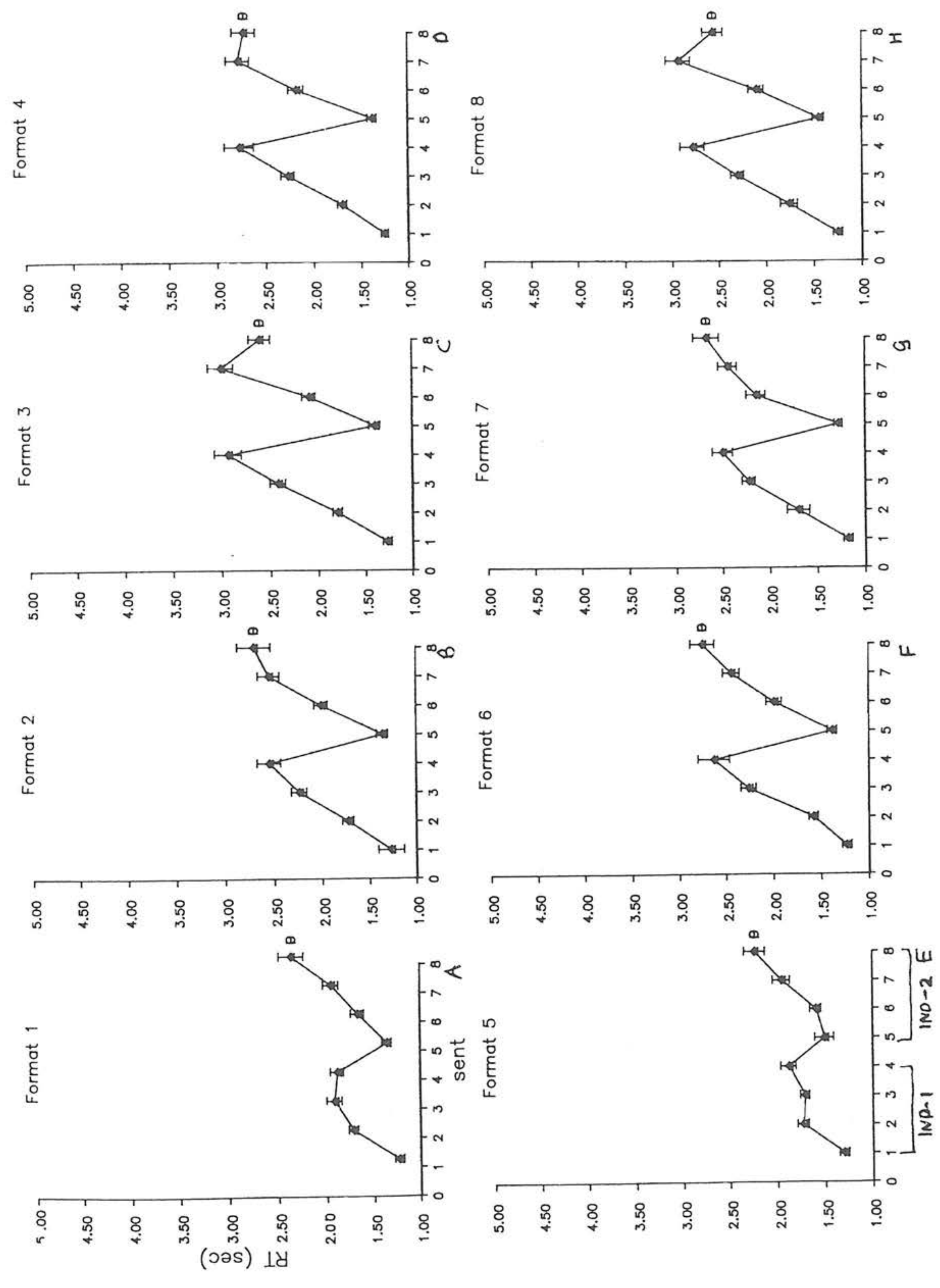
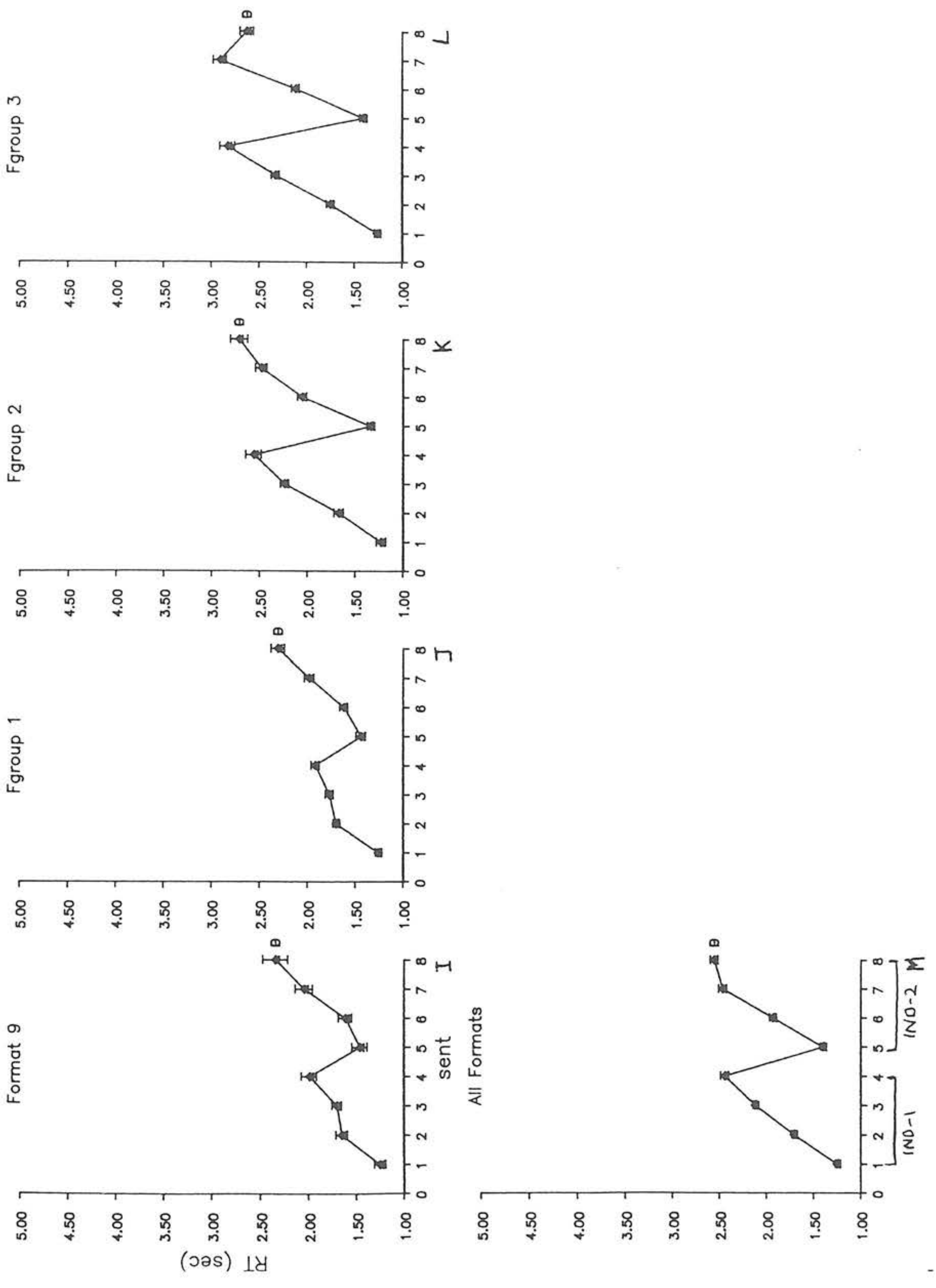


Figure 2: Mean reading times of predicates by individuals



In order to see if the difference between reading times of formats within format group are significant three separate ANOVA's for each format group were also carried out. Except for format (3 levels) all other factors and levels were same as the main ANOVA. All three show that within each format group mean reading time differences are not significant which confirms that differences in dimension order of predicates of each individual has no significant effect on reading times. The **F**-ratios, **F** (2,36) = 0.18, **F** (2,36) = 0.24 and **F** (2,36) = 0.56 for format groups 1, 2 and 3 respectively, are all not significant at $p < 0.05$. Within these groups, format does not significantly interact with any other factors except in format group 1 where the interaction between format, matchtype, predicate and individual is significant (**F** (42,756) = 1.51, $p < 0.05$). However, format does not significantly interact with any of these factors individually. Thus it seems likely that this overall interaction reflects the highly significant interaction between matchtype, predicate and individual (**F** (21,378) = 7.57, $p < 0.0001$) which it subsumes.

The rest of the findings reported in this section are based on an ANOVA of the mean reading times collapsed across formats in each format group. Instead of format we had format group as a fixed factor (3 levels). As expected there is a main effect of format group (**F** (2,36) = 40.36, $p < 0.0001$). The means were 1.75, 2.03 and 2.15 seconds per sentence in texts in format groups 1, 2 and 3 respectively. The significant differences in reading times are therefore due to higher level semantic differences due to the temporal order of individuals' attributes rather than different dimensions presented in the same sentence position in texts. We have already explained the effect of temporal order on the availability of matchtype information. Thus, at this stage we can suggest that the observed increase in sentence mean reading times for format groups 2 and 3 reflect the extra processing necessitated by the relative lack of matchtype information during the earlier parts of texts; apart from the first mismatch subjects do not have any matchtype information till the fifth and the sixth sentences of texts in format groups 2 and 3 respectively. Reading time means of format group by predicate are given in Table 3 and illustrated in Figure 2 (graphs B-D).

Table 3

Means of predicates by individual within format group

	Individual 1				Individual 2				All
Predicate:	1	2	3	4	1	2	3	4	Predicates
Format group: 1	1.26	1.70	2.24	2.56	1.44	1.62	1.98	2.31	1.78
2	1.23	1.67	2.24	2.56	1.34	2.05	2.48	2.71	2.03
3	1.26	1.75	2.33	2.83	1.41	2.12	2.91	2.63	2.15
All formats	1.25	1.71	2.12	2.44	1.40	1.93	2.46	2.55	-

There is a main effect of predicate (F (3,54) = 27.62, $p < 0.0001$). Means collapsed across individuals were 1.32, 1.82, 2.29 and 2.49 seconds for predicates 1 to 4 respectively. This shows that the temporal order of predicates, independent of the attribute dimension, has a significant effect on reading times. This result shows that the Semantic Ordinal Effect is due to the temporal position of the predicate and not due to any particular order of dimensions in which individuals are described.

There is a main effect of individual (F (1,18) = 15.03, $p < 0.001$). Overall, the first presented individual's mean reading time is significantly faster than that of the second individual (1.88 and 2.08 secs. respectively). The interaction between predicate and individual is not significant (F (3,18) = 0.97). This indicates that though there are some differences in the rate of increase in reading times of predicates of each individual, the direction of increase does not vary significantly, which supports predictions based on previous observations of the Semantic Ordinal Effect.

There is a main effect of matchtype (F (7,126) = 9.18, $p < 0.0001$). Sentences of texts presented in matchtype pattern 1 (+++) on average took the shortest time to read (1.78 seconds) and those presented in matchtype pattern 4 (+--) took the longest (2.10). Means for other matchtypes are given in Table 4. It is clear that matchtype has a significant effect on sentence reading times though at this stage it is difficult to identify particular aspects of matchtype structure which affect processing loads during construction of representation. The total number of matched or mismatched dimensions in a text is not a good predictor of sentence reading times. In this experiment this issue is further complicated by format groups' effect on temporal order in which matchtype information becomes available, which accounts for the highly significant interaction between format group and matchtype (F (14,252) = 4.22, $p < 0.0001$). The means are given in Table 4.

Table 4

Mean reading times of matchtype by format group

Matchtype	1	2	3	4	5	6	7	8	All Matchtypes
Format group: 1	1.38	1.56	1.64	1.85	1.78	1.95	1.88	1.97	1.75
2	1.86	1.90	2.05	2.26	2.13	2.09	1.97	2.02	2.03
3	2.10	2.11	2.33	2.19	2.20	2.14	2.10	2.06	2.15
All formats	1.78	1.86	2.00	2.10	2.04	2.06	1.99	2.02	

The interaction between format group and predicate is significant (F (6,108) = 12.63, $p < 0.0001$). Encoding predicates in a representation is affected by temporal order of sentences in a text. The interaction between matchtype and predicate is also significant (F (21,378) = 4.10, $p < 0.0001$). This shows that the effect of matchtype information on reading times varies according to the temporal order of predicates.

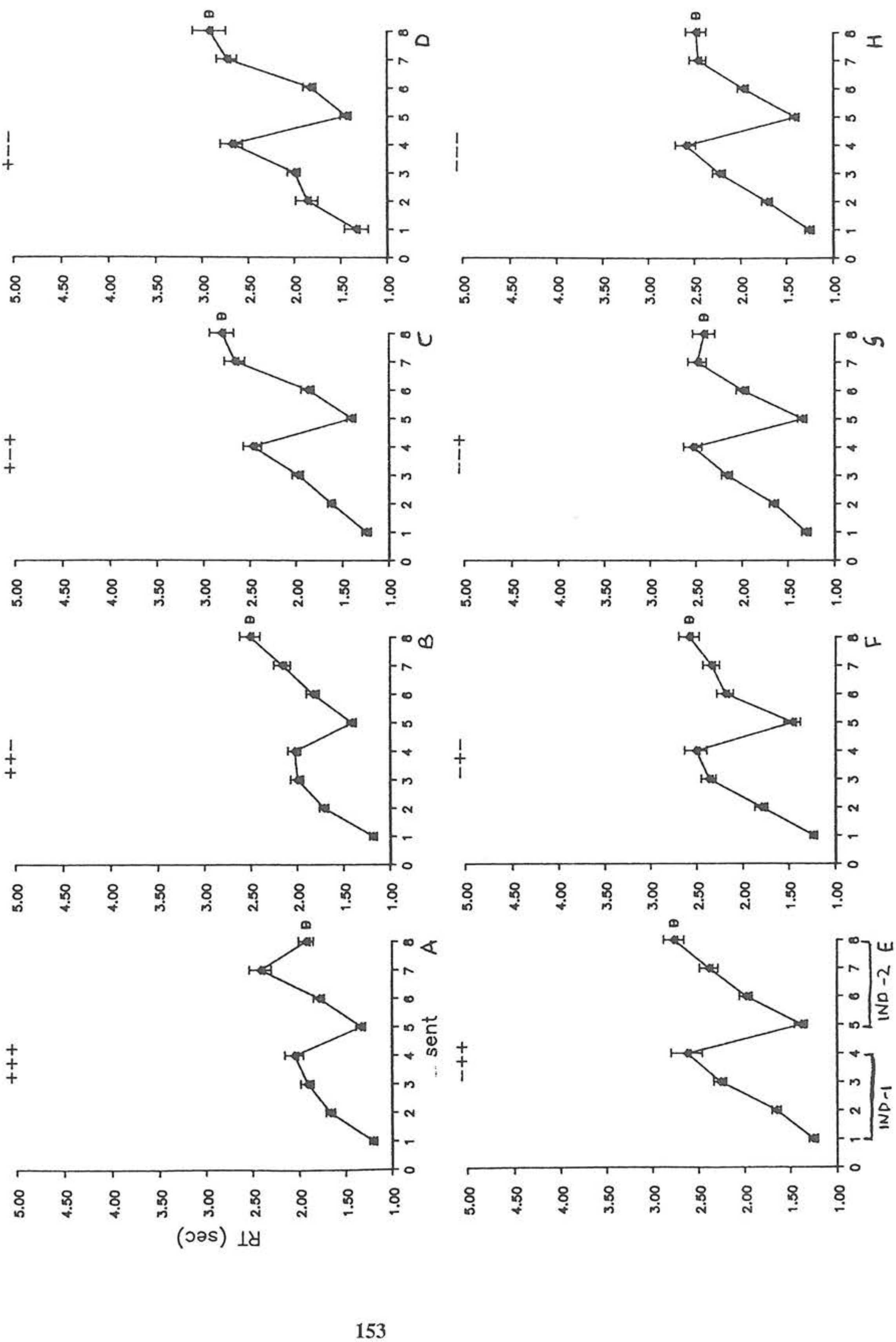
The interactions between individual, predicate and format group (F (6,108) = 6.56, $p < 0.0001$); individual, matchtype and predicate (F (21,378) = 2.98, $p < 0.0001$); and, individual, matchtype and format group (F (14,1008) = 2.45, $p < 0.003$) are all significant. The mean reading times of predicate of each individual by matchtype are given in Table 5 and illustrated in Figure 3 (graphs A-H). The graphs illustrate that in most cases reading times increase in line with the number of predicates. Exceptions include unexpected drops in mean reading times between the third and fourth predicates of the second individual in matchtypes 1 and 7 (Figure 3, graphs A and G). In both cases the presented attribute is matched which suggests that subjects are not bothering to encode the information in the partially constructed representation of preceding attributes, and relying on the sort of redundant information which was described above.

Table 5

Mean reading times of individuals predicate by matchtype

		Individual 1				Individual 2				All
	Predicate	1	2	3	4	1	2	3	4	Predicates
Matchtype:	1 (+++)	1.20	1.66	1.91	2.05	1.33	1.78	2.42	1.92	1.78
	2 (++-)	1.18	1.71	2.00	2.03	1.41	1.83	2.17	2.51	1.86
	3 (+-+)	1.24	1.62	1.98	2.47	1.40	1.87	2.66	2.80	2.00
	4 (+--)	1.33	1.86	2.00	2.68	1.44	1.83	2.75	2.93	2.10
	5 (-++)	1.25	1.65	2.26	2.62	1.38	1.98	2.38	2.76	2.04
	6 (-+-)	1.23	1.80	2.37	2.51	1.46	2.19	2.34	2.58	2.05
	7 (--+)	1.30	1.66	2.16	2.53	1.34	1.99	2.49	2.41	1.99
	8 (---)	1.25	1.71	2.24	2.59	1.41	1.97	2.46	2.48	2.02
All Matchtypes		1.25	1.71	2.12	2.44	1.40	1.93	2.46	2.55	

Figure 3: Mean reading times individual predicates and matchtype



The interaction between format group, matchtype, individual and predicate is also highly significant (F (42,756) = 2.24, $p < 0.0001$). At this level of complexity this is not very illuminating, and shows that everything is affected by everything else. The development of the regression model will enable us to identify some of the factors that contribute to the significance of this interaction.

To summarise, the above analyses of the reading time data support two major conclusions. First, different dimension orders within format groups have no significant effect on reading times. For example, whether the second sentence describes the nationality or the stature attribute of an individual has no significant effect on reading time. This finding concurs with that of the previous study where we also found that format did not interact with other factors. This result supports our working distinction between content and higher level semantic information. It validates the study of the latter independent of the former, at least within the highly constrained paradigm of the nature of the solution to the binding problem in the MIT.

Second, the results highlight the major effect of *temporal order* of predicates of each individual on reading times, confirming that Semantic Ordinal Effect reflects the increase in processing loads due to the construction of increasingly elaborate representational structure required to bind attributes of an individual. Further, it clearly shows that the most important determiner of reading times is the order in which *each* individual is described; in other words, *format group* rather than *format* is by far the most significant factor in determining processing loads. Differences in this aspect of a typical MIT text, as has already been pointed out, affect the availability of information about matchtype structure. In the next section we present the results of regression analysis, and return to a more thorough discussion of the effect of format group on subjects' strategy of building representational structures incorporating information about matchtype structure.

5. Development of regression model

A regression model was developed to model the effect of matchtype information and format group on reading times. As in Chapter 2 it is assumed that subjects utilise matchtype information to construct appropriate representational structures to solve the binding problem. Most regression variables are similar to those used to develop Model 1. The underlying assumption for all these recurrent loads is that they do not represent the same processes but the same sort for the same type of semantic structures; MISLOAD, MATLOAD and NEUTLOAD which distinguish between loads imposed by particular aspects of matchtype information were included. They represent their cumulative loads at specific points in the text. The loads in working memory are assumed to increase as the numerical value of these variables increase.

In the last experiment, NEUTLOAD referred to the number of neutral properties that are known about the *currently referenced* individual, but which are unresolved in terms of matching status of their dimensions. This was because at any stage in the text the number of unresolved properties referred to only one individual; a reader at no time learnt about attributes of both individuals, and since their dimension orders were identical, unresolved properties of the background individual contributed to processing associated with the matching status information of the attribute dimension of the currently referenced individual. In this study we have a novel situation whereby unresolved properties on the background individual can remain unresolved when the currently referenced individual is described by an attribute from a different property dimension. >From reading time data it was clear that unresolved properties of the currently non-referenced individual contributed to processing loads. The rise in reading time between the 3rd and 4th sentences in format group (from 1.75 to 2.12 seconds) is one such example. According to the definition of NEUTLOAD in Model 1 both would take a value of 1 at these sentence positions, which fails to reflect possible effects of unresolved properties of the background individual. Hence, the definition of NEUTLOAD was extended to take account of the cumulative effect of unresolved properties of both individuals. Thus for this model unresolved properties are assumed to have a cumulative effect across individuals. For instance, three unresolved properties, independent of the individuals they describe, are predicted to need more processing than two unresolved ones.

A new variable, MATLOAD-PLUS, was also offered to take account of the effect of format on processing load. A closer look at both, the observed pattern of rise in reading times, and residuals indicated that matched attributes at particular positions in texts in format groups 2 and 3 took unusually long to read. At sentences 8 and 6 in format groups 2 and 3 respectively, where subjects learn about the matching status of the fourth and second property dimensions respectively, mean reading times for matched attributes are higher than mismatched ones. See Table 6, where asterisks identify sentences at which information about matching status becomes available or resolved. Means for the first dimension (profession) which is always mismatched are not included.

Table 6

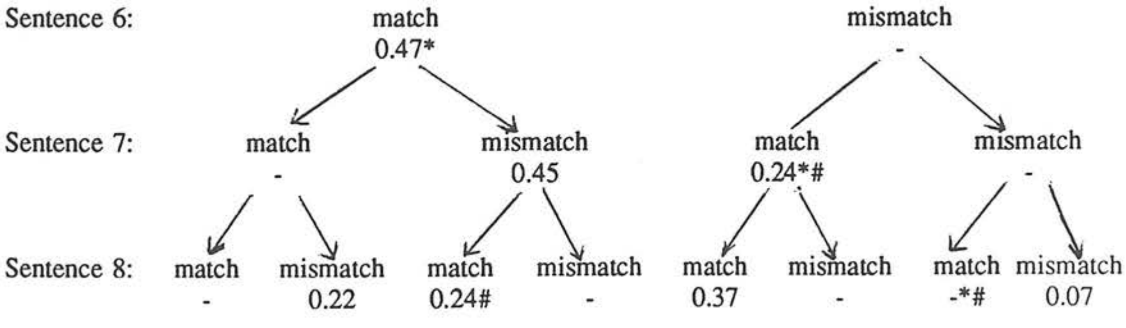
Mean reading times of matched and mismatched properties by format group

Sentence		3	4	5	6	7	8
Format group: 1	matched	1.70	1.62*	1.78	1.57*	1.88	2.01*
	mismatched	1.71	1.99*	1.77	2.39*	1.97	2.61*
2	matched	1.57	2.07	2.01*	2.49	2.41*	2.74*
	mismatched	1.78	2.02	2.47*	2.47	2.71*	2.68*
3	matched	1.73	2.15	2.33	3.14*	2.77*	2.67*
	mismatched	1.78	2.10	2.33	2.67*	2.88*	2.59*

More detailed analysis of the data in format group 3 suggests that matched properties at sentences other than 6 also tend to take longer to encode than mismatched properties. The diagram in Figure 4 illustrates this more clearly by showing the absolute differences in mean reading times between matched and mismatched property dimensions at sentences 6, 7 and 8 of texts in format group 3. It should be read from top down (following the arrows) as each possible pathway corresponds to one of the eight matchtype structure patterns. This enables us to see the difference in the effect of matched and mismatched properties on reading times in temporal terms. The *first* matched property dimension at sentences 6 and 7 (denoted by *) take longer to read than a mismatched property (0.47 and 0.24 seconds respectively). However, this is not the case for sentence 8 where mismatched properties take slightly longer to read (0.07). This is also an exception to the fact that other matched properties after a mismatch take longer to read than mismatched properties at that sentence position (denoted by #). This illustrates that matched attribute dimensions in format group 3, in particular, tend to have higher reading times than mismatched dimensions, which is highly unusual in light of results of previous studies where the opposite has been the norm. The most likely reason being those given in the introduction to this Chapter.

Figure 4

Absolute differences in mean reading times between matched and mismatched dimensions in format group 3



What likely processes does MATLOAD-PLUS represent? Since the observed reading times means are as high or even higher than those for mismatched property dimensions, it seems highly likely that a larger than usual number of associations are being recruited to represent matched attributes. In format group 3 at sentence 5 (excluding the introducers) the subject already knows about three other properties, two belonging to the first individual and one to the second individual, and no information about their matching status. In which case only intra-individual associations can be recruited. Such a partial representation may make it difficult to assimilate matchtype information which becomes available at sentence 6, in which case they would carry on relying on intra-individual links to represent a solution to the binding problem. If so, the increase in processing loads suggested by peak reading times would reflect a representation strategy different from the one assumed on the bases of previous studies. If subjects are relying solely on intra-individual links then mismatched properties would be relatively straightforward to encode as they would be different from all the other known properties of both individual. However, for matched property the reverse would be the case because that would open up the possibility of confusion over other attributes of both individuals. For example, if one already knows that the chef is tall and mad, and that the vet is Swiss, and then learns that the vet is also tall, it would be easy to confuse the attribute "tall" that goes with "mad" with the one that goes with "Swiss". To minimise the possibility of this sort of interference a reader would devote more processing to construct robust structures in the representation. This view is supported by the higher number of possible associative links needed to distinguish between each individual's attributes. Apart from encoding *A*, *~A*, *AB*, *~AC*, *ABD* and *subjects would have to explicitly encode the fact that it is not the case* that *ABC* or *In the case of a mismatched property dimension*, *B~B*, the last two bindings are superfluous.

In format group 2 at sentence 8 by which stage the representation is almost complete a similar account can be given to explain the relatively high reading time means for matched attributes, which are presented at the third sentence for the first individual and the eighth sentence for the second one. In between these two sentences subjects learn about the remaining two property dimensions. During this process the property at sentence 3 has already been encoded with a number of intra-individual associations. In which case, matched attributes at sentence 8 would be more efficiently encoded as bound to other attributes of the second individual, and the increase in processing load reflects the representational structures needed to avoid possible interference and confusion during retrieval.

To summarise, matched attributes are not explicitly encoded as such and are potentially more confusing because not only does a reader have to encode more intra-individual links to associate with other attributes of the relevant individual, but she also has to ensure against possible confusion between attributes of each individual which can result from phonemic and semantic similarity of matched attributes. Wickelgren (1965, 1966), for example, reports how a string of phonemes with similar vowel sounds result in more recall errors than for different vowel sounds. The significant difference in errors is explained in terms of the relative differences in the number of associative links between vowel sounds and consonants. His model predicts that the possible number of links between vowels and consonants is less when the vowel sound is the same then when it is not, which is likely to lead to more confusion at during retrieval. In the present study this kind of similarity does not usually result in interference because the semantic structures of stimuli texts is a lot richer. In the exceptional cases subjects overcome the potential problem by devoting more processing to construct appropriate associative links in order to solve the binding problem. If the extra processing reflects a greater reliance on intra-individual associative links, then we can make two predictions about recall errors. First, subjects will make higher errors in format groups 2 and 3. Second, error patterns, particularly for matched properties will reflect both, the lack of inter-individual links and the predominance of intra-individual links. Recall error results reported in Chapter 6 support both these predictions.

MATLOAD-PLUS, was offered for selection in the multiple regression analysis. This variable takes a value of one for matched dimensions at sentences 8 and 6 in texts in format groups 2 and 3 respectively. Like all other matchtype structure variables, MATLOAD-PLUS's value is recurrent and cumulative; the processing load associated with it is assumed to be present at all subsequent sentence positions. MATLOAD-PLUS and MATLOAD are mutually exclusive, though MATLOAD takes a value at sentences 7 and 8 in format group 3 where MATLOAD-PLUS may apply as well (see Table 7).

Previous multiple regression models of mean reading times of texts presented in P x P order included a local variable, LOCALMIS, which took into account the contribution of detecting a mismatched dimension. Though texts were presented in P x P order in this study the effect of locating a mismatch was confounded with that of other processing loads associated with the format group on the construction of representations. The regression model presented here does not include LOCALMIS. However, individual models of within format group reading times show that LOCALMIS gets selected for format group 1, but not 2 and 3. This outcome is consistent with our earlier suggestion that LOCALMIS represents processes associated with recognising a mismatched dimension which, of course, is the easiest in format group 1 since it is closest to the P x P mode used in, among others, the SSL study.

Table 7 shows three examples of the loads assigned by all four variables, MISLOAD, MATLOAD, NEUTLOAD and MATLOAD-PLUS, at each sentence in texts presented in the format groups. The first text is in format 1 (format group 1) and is mismatched on the first, third and fourth dimension. The second one is in format 2 (format group 2) and is mismatched on the first and second dimensions. The third one is in format 3 (format group 3) and mismatched on all except the second dimension. A complete list of all variables load assignment in each format group for texts in all eight match-type pattern is given in Appendix G.

Table 7

Three example of values taken by each variable.

Text	MISLOAD	MATLOAD	NEUTLOAD	MATLOAD-PLUS
Format 1 +--				
There is a nurse	0	0	1	0
There is a priest	1	0	0	0
The nurse is Swedish	1	0	1	0
The priest is Swedish	1	1	0	0
The nurse is thin	1	1	1	0
The priest is fat	2	1	0	0
The nurse is strong	2	1	1	0
The priest is weak	3	1	0	0
Format 2 -++				
There is a nurse	0	0	1	0
There is a priest	1	0	0	0
The nurse is welsh	1	0	1	0
The priest is clever	1	0	2	0
The nurse is stupid	2	0	1	0
The priest is strong	2	0	2	0
The nurse is strong	2	1	1	0
The priest is welsh	2	1	0	1
Format 3 +--				
There is a baker	0	0	1	0
There is a dentist	1	0	0	0
The baker is polish	1	0	1	0
The dentist is happy	1	0	2	0
The baker is poor	1	0	3	0
The dentist is polish	1	0	2	1
The baker is gloomy	1	0	1	1
The dentist is rich	2	0	0	1

5.1. Selecting and fitting regression model

A general regression model was developed for all formats. The selection of best-fitting model was performed by program P9R of the BMDP package, using Mallow's CP statistics (Dixon et al, 1968, 1983). Definition of variables used in the regression model were as follows:

(1) MISLOAD is the number of mismatches on the referenced individual. This factor was expressed as dummy variables MIS1, MIS2, MIS3, MIS4. Each had a value of 1 if MISLOAD's value corresponded to its number, otherwise its value was 0.

(2) MATLOAD is the number of matches on the referenced individual. This factor was expressed as dummy variables MAT1, MAT2 and MAT3, in the same manner as MISLOAD.

(3) NEUTLOAD is the number of unresolved properties on the referenced individual which cannot be assigned as matches or mismatches with the background individual. This factor was expressed as dummy variables NEUT1, NEUT2, NEUT3 and NEUT4 in the same manner as MISLOAD.

(4) MATLOAD-PLUS is the number of matches separated by at least two other unresolved properties or (matched or mismatched) dimensions on the referenced individual. Since in this study it never takes a value greater than 1, it was expressed as a binary variable.

6. Reading time regression model results

The regression model selected all variables. Table 8 shows these variables and their coefficients and standard errors. The contribution of each variable to $\mathbf{R}^2$ is significant ($p < 0.01$). Pure error accounts for 89.7% of the total variance. Of the remaining variance, the regression model accounts for 95.3%, leaving a 0.49% lack of fit. This is a better fit to the observed data than that of Model 1.

Table 8

Summary of regression model predicting reading times from matchtype structure and format

Variable	Coeff.	Standard Error
Intercept	0.97	.041
NEUT1	0.28	.027
NEUT2	0.74	.034
NEUT3	0.96	.058
MIS1	0.40	.038
MIS2	1.00	.042
MIS3	1.35	.052
MIS4	1.51	.095
MAT1	0.21	.029
MAT2	0.30	.044
MATLOAD-PLUS	0.64	.042

Figure 5 (graphs A-H) and Figure 6 (graph A) show the observed and predicted reading times at each individual attribute and format. This gives a good indication of the effect of format on the processing of both individuals. From the graphs it is quite clear that the model is better at predicting reading times for texts in certain formats. Figure 6 (graphs B, C and D) show the observed and predicted reading times collapsed across format groups. The model's prediction of reading times of texts in format group 1 is not as good as that for the other two formats. This reflects the the model's predictive bias based on the higher reading times observed for sentences in format groups 2 and 3 which makes up two third of all the data. The predicted coefficients of MISLOAD and NEUTLOAD are generally higher then those predicted by Model 1 which is an indication of higher processing loads due to the effect of format group. Figure 6 (graph M) shows the general fit of the model's predicted reading times to the observed mean reading times collapsed across format, indicating that the combination of independent variables selected by the model provide a good account of format's overall effect on the Semantic Ordinal Effect.

Figure 7 (graphs A-H) shows the observed and predicted reading times at each sentence position for each matchtype. It indicates the impact of matchtype on the processing of one individual in terms of the other.

Figure 5: Observed and predicted reading times of predicate by format

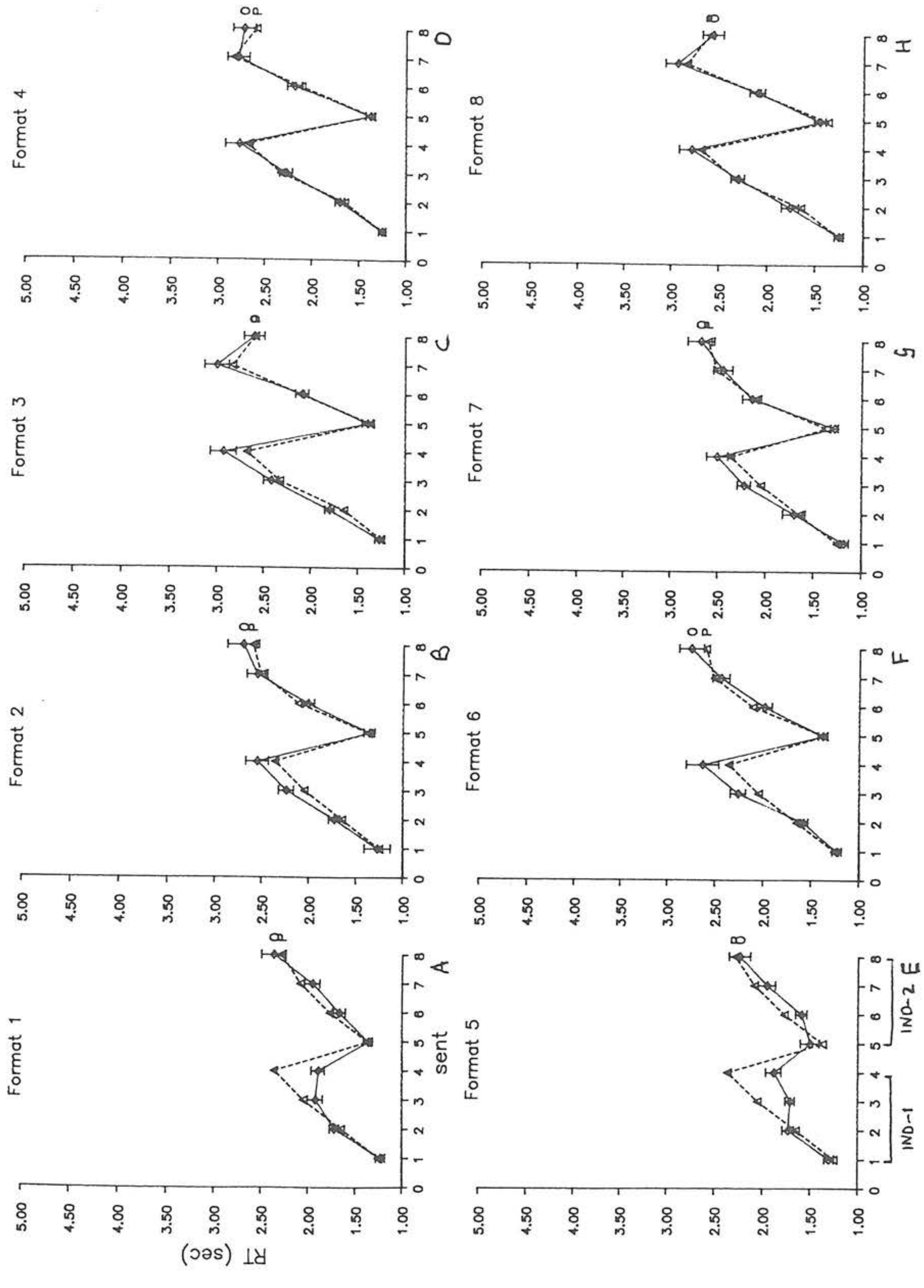


Figure 6: Observed and predicted reading times of predicate by format

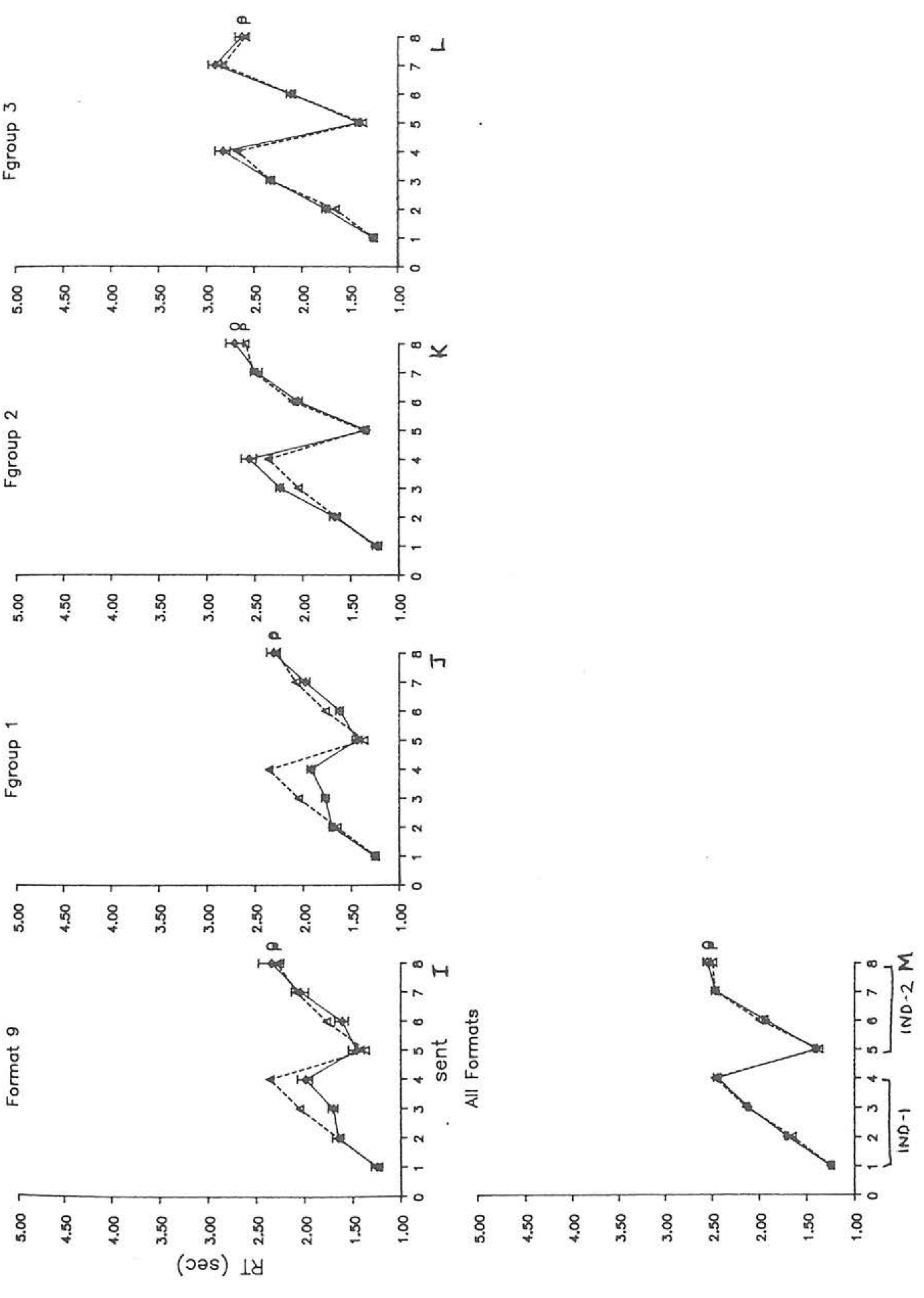
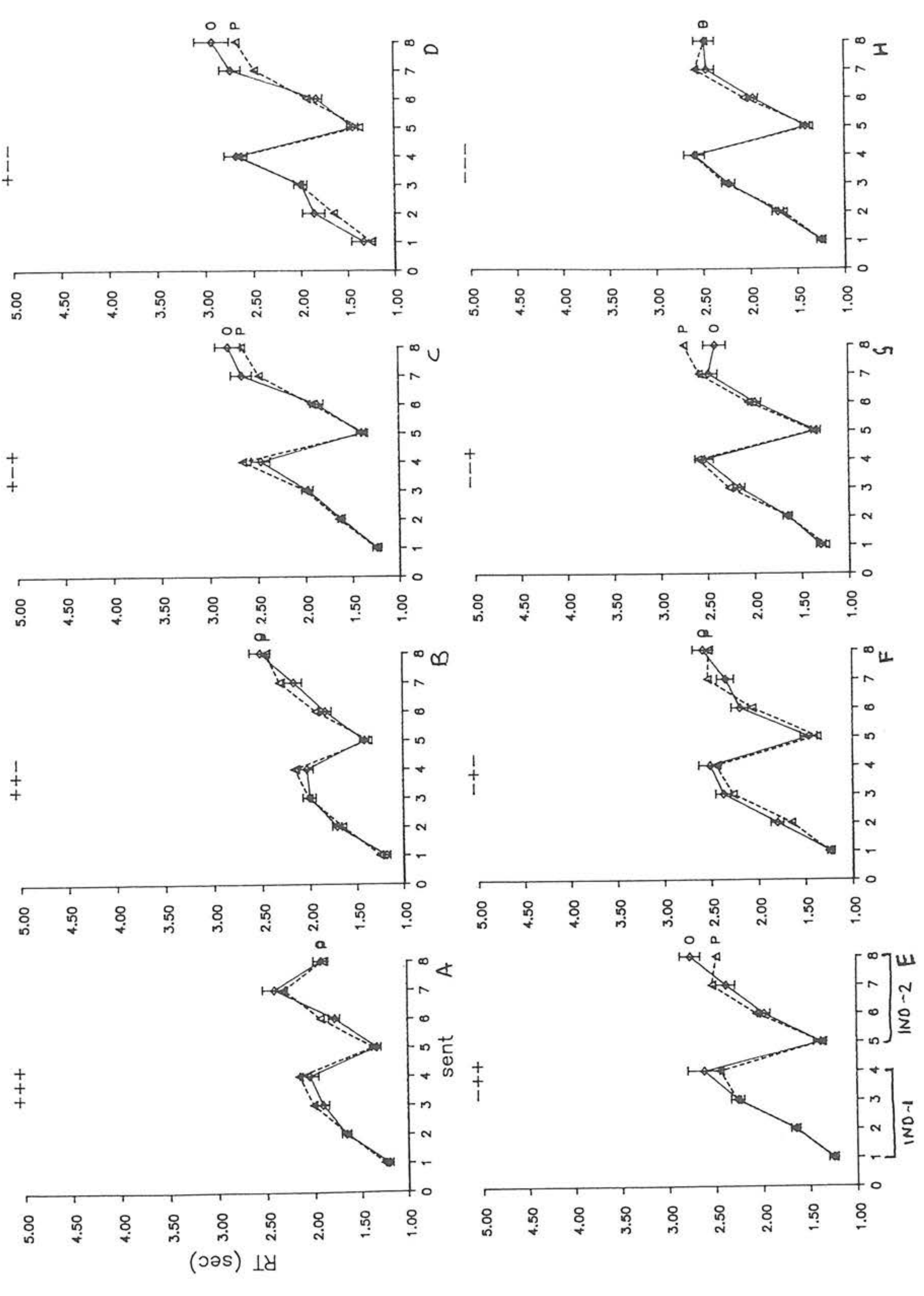


Figure 7: Observed and predicted reading times of predicate by matchtype



The model selected dummy variables corresponding to all levels of NEUTLOAD and MISLOAD, two out of three levels of MATLOAD, and, MATLOAD-PLUS. MAT3 was probably not selected because it only took a value at one sentence in one eighth of all texts in format group 1. In format groups 2 and 3 MAT3 never took a value because of MATLOAD-PLUS which had a value of one instead. All three variables take a value at more than one different point in the texts in all format groups, and in different combinations with or without other variables. (See Appendix G).

Compared to Model 1 (see Table 6 in Chapter 2) matchtype information makes a much larger contribution to processing loads associated with the construction of a representation. MISLOAD's contribution to reading time rises as the number of mismatches increase (from 0.40 seconds for MIS1 to 1.51 seconds for MIS4). The shape of the curve is a much steeper than that predicted by Model 1 though it is lot more similar to the one predicted by the SSL Model. The higher coefficients for levels 2, 3 and 4 of MISLOAD indicate the effect of format group on processing. Part of the contribution to higher reading times may be an effect of experimental task, since the overall reading time curve for texts in format group 1 is not as steep as the one observed for P x P mode texts in the SSL study. The shape of MATLOAD function which rises by a small amount between the first and second level (0.21 and 0.30 seconds respectively), is not as steep as that predicted in the SSL model (see Table 4 in Chapter 2).

NEUTLOAD's predicted contribution is similar to that in the SSL model, though the rise between the first and the second level is unusually steep. This can be accounted for by the limited number of instances of NEUT2 which only take a value on the second individual. Offering two separate variables for each individual did not alter the predicted coefficients. Nevertheless, the important observation is that the predicted rising function supports our hypothesis based on previous findings that, the more unresolved properties there are the bigger the processing load.

The MATLOAD-PLUS's predicted coefficient of 0.64 seconds suggests that extra processing associated with this variable is quite large. The nature of processing subsumed under this variable is given further consideration in the next section.

7. Discussion

Sentence reading times replicate the Semantic Ordinal Effect. This shows that at a general level the construction processes of representations of individuals are not affected by format. These processes are independent of the dimension of property attributes of individuals. However, the temporal order in which each individual is described in a text has a significant effect on processing, which highlights the major role of information about matchtype structure in the representation of a solution to the binding problem. In particular, differences due to format group reflect the increasing complexity resulting from a less direct access to matchtype information. The regression model provides further support for the modularity of processes of construction. The variables, MISLOAD, MATLOAD and NEUTLOAD, represent processes which bear close similarity to those assumed in Model 1.

The finding that different lexical items presented in the same temporal position do not have significantly different reading times is an important one for our approach to the study of text processing and knowledge representation. It replicates results of the effect of format on reading times in the last study. Both results justify our concentration on the role of higher level semantic information in text processing. They show that notwithstanding the obvious importance of content on general knowledge recruited in representations constructed during text processing, it is legitimate and worthwhile to investigate the other major contributor to representation structures. In other words matchtype information is indicative of how property attributes are represented, and it is a type of relational structure information which plays an important role in text comprehension. In this present case, that is the manner in which properties attributed to one individual are bound together in a representation, and more specifically, in the case of an MIT text describing two individuals how matchtype information determines the sorts, number and complexity of inter- and intra-individuals associations recruited to represent clusters of property attributes of individuals.

As with others, the regression model confirmed that processes associated with the selected variables are distinct and independent of the history of processing. This holds even if some of the predicted loads are higher (more time consuming) than those observed in other studies. What does the higher predicted reading times indicate? Does it reflect an increase in loads due to a larger number of unresolved properties, or the general increase in the number and complexity of associations between properties encoded to compensate for the delay in matchtype information? The development of this model indicates that it is both, and that the dichotomy underlying the question is more apparent than real since an increase in the number of unresolved properties early on in the text is highly correlated with the delay in availability to matchtype information. Overall the model reveals how matchtype information can influence a readers strategy of constructing representations. In cases where the information is presented in a relatively straightforward manner, as it is in format group 1, subjects utilise it to encode the necessary associations between attributes of individuals. It would seem that sometimes it is used to encode superficial relationships between properties. MATLOAD, but not MATLOAD-PLUS, as defined here may reflect the process of representing the fact that one property on a particular dimension describes both individuals, dispensing with the time consuming process of assimilating this information as part of the representation structures of other known properties of individuals. This aspect of MATLOAD will be discussed further below, the important point is that on the whole our model predicts an inverse relationship between ready availability of matchtype information and the load on construction processes of representation. Where it is not so readily available, as in format groups 2 and 3, it leads to an increase in sentence reading times. We will consider each variable in light of this prediction, and in so doing attempt to give a more precise account of how the increases in loads can be explained in terms of the sorts of associations recruited to accommodate the effect of unresolved properties.

Given our preferred account of MISLOAD as representing processing load of recruiting intra-individual associations, the most appropriate account for the higher predicted loads is that readers have less opportunity to rely on redundancy similar to that suggested by the function of the reading time curve predicted by Model 1. It indicates that more intra-individual associations are being constructed. This does not imply that MISLOAD represents qualitatively different sorts of processes compared to the SSL model, but that because the dimension orders were not fixed using mismatching information is more costly. The other side of the coin is that unresolved properties make it more time consuming to use this information. It seems to be the case that unlike the SSL model, readers recruit more intra-individual associations because more would be necessary by the time this information becomes available. This account is highly consistent with the fact that while reading times of the second mismatch are very different in each format group, those for the fourth (last) mismatch where there are no unresolved properties are very similar (2.61, 2.68 and 2.59 respectively).

The first predicted coefficient of NEUTLOAD is identical to that predicted by both, Model 1 and the SSL model, which confirms our assumed similarity between these processes in different studies. However, as we have already seen, NEUTLOAD, in this study takes a value across individuals. This is another consequence of format group which leads to higher processing. Compared to Model 1 the higher value of NEUT2, which takes a value only on the second individual in format groups 2 and 3 and none in format group 1, represents the combined effect of unresolved properties belonging to two different individuals. This difference in the loads reflects the more elaborate intra-individual associations required to represent facts about two separate individuals; for example, instead of representing the simpler proposition that one individual, *x*, has the property attributes *A*, *B* & *C*, the reader has to encode two different propositions that one individual, *x*, is *A* & *B* and that the second individual, *y*, is *The present model predicts that the simultaneous representation of* unresolved properties belonging to two different individuals requires extra processing not observed in previous studies. Offering two separate variables to account for this difference was not very illuminating since the predicted coefficient for the equivalent of NEUT2, that is NEUT1 of the second individual, had the same high coefficient which is not surprising given that it only ever takes a value on the second individual. The prediction that an unresolved property of the second individual requires more processing than one describing the first individual would suggest that each individual is processed differently and have a separate existence in the representation which would contradict our basic understanding of text comprehension. Further, a model with two variables does not fit the data as well as the combined one used here (93.2% as opposed to 95.5% of this one). Apart from being difficult to reconcile with Model 1, this would effectively suggest that an unresolved property on the background individual had no effect on the current individual which evidently is not the case. This is an interesting issue and a more detailed explanation of this novel aspect of the nature of processing loads due to unresolved properties is not possible till an experimental study in which the all possible values of NEUTLOAD would occur on both individuals is carried out.

The relatively high processing load associated with MATLOAD-PLUS can readily be explained in terms of the increased number of associations required to overcome the potential from proactive or retroactive interference. The model's prediction supports the reasons for its motivation, and in the next Chapter we will see how the sort of interference that this process is designed to overcome has interesting effects on representation structures of texts processed in formats 2 and 3. What, however, is not obvious is its relation to MATLOAD, which can be characterised as representing a process of recruiting associations that are less prone to interference. Why should this be the case? There are two possibilities for this state of affair. The first one is that each variable represents different sorts of processing with MATLOAD as more akin to a simple binary variable such as LOCALMIS, which is local and non-cumulative. Thus it would represent the process of recognising a mismatch rather than any more elaborate encoding of intra-individual associations. This definition of MATLOAD is closer to the one used in SSL and consistent with our account for its exclusion from Model 1. However, on being offered such a binary variable, LOCALMAT, the resultant model did not have as good a fit to the data, so clearly MATLOAD represents a cumulative processing load. In which case, the second possibility that MATLOAD-PLUS subsumes processing represented by MATLOAD as well as extra processing to overcome possible interference during retrieval, is more likely. Though MATLOAD represents processing which is cumulative, the small difference between MAT1 and MAT2 reflects a strong possibility that the load is only partly due to the construction of more elaborate structures in representation, which renders MATLOAD slightly different from MISLOAD and MATLOAD-PLUS. If MATLOAD is a simple process of cumulative identification of matched property dimensions then it is compatible with the definition of MATLOAD-PLUS. This account of the relationship between MATLOAD and MATLOAD-PLUS is difficult to substantiate by using multiple regression modelling technique for two reasons. Both variables' definitions are very similar, and therefore, could not be simultaneously offered for selection by the regression model, and further, MATLOAD-PLUS only takes a non-zero value at a relatively small number of places which makes it difficult to compare and contrast these two variables.

More general discussion on the effect of format and format group on the resolution of the binding problem in MIT appears at the end of the next chapter in which we present findings of analyses of recall error data, and regression models of the relative saliency of encoded semantic features in representations.

Chapter 6

1. Introduction

In this chapter we turn to observed recall error data of the second study. As before, the aim is to develop models of representation structures necessary for a solution to the binding problem for texts in different formats. Reading times analyses, presented in the Chapter 5 show a clear and significant effect of format group on construction processes. Further, analysis for the effect of rehearsal on reading time, gave a strong indication that much of this effect was due to processing related to semantic structural information, which in MIT texts is matchtype information. The reading time model (Model 3) suggests two ways in which this effect can be factored out. The first is the effect of matched properties on processing, and the second, is the generally higher predicted coefficients for MISLOAD and to a lesser extent NEUTLOAD. In discussing these findings it was pointed out that these predicted reading time differences would be reflected in differences in observed error patterns, and therefore, representation structures. Since our models of representations are based on the observed error patterns we will be taking a close look at the error data in order to seek out any systematic differences in errors due to format group, and its critical counterpart, differences in availability of matchtype information. For reasons given in Chapter 4, all models of representations are of indirect features.

1.1. Format groups and recall errors

Format groups affect accessibility and availability of information about matchtype structure. This interaction is the basis for differences in reading time means of texts in different format groups. Model 3 predicts most of these effects as increased loads due to differences in where the matchtype status of a particular property dimension is resolved; *when* a reader has this information, and, *what* else she knows about each individual, has a significant effect on construction processes in working memory. The main question here is, does this have an effect on the sorts of associations recruited in the constructed representation of a solution to the binding problem? Do the underlying semantic features suggested by observed error patterns reflect differences due to text formats?

If information about matchtype structure functions solely as extra redundancy in the representation, and if it is less readily available, then a reader would be expected to change her representation strategy when performing the MIT. In this simple case, recall errors would be be expected to increase, since we assume that redundancy would enhance performance during retrieval. However, at this stage it is clear that the role of higher order semantic structures such as, matchtype information, is far more complicated, and that it is an important determiner of the intra-individual associations between attributes of individuals. Further, Model 3 predicts that text processing is sensitive to information about matching status of property dimensions. Higher predicted reading times for MISLOAD and NEUTLOAD suggest that in some format groups the processing load of this information is affected by a possible increase in the number of associations between properties of individuals. In this case, recall errors would be expected to be similar for all format groups if the extra processing was sufficient to overcome the difficulty in binding properties due to a lack of matchtype information.

Recall errors show a number of different effects of format groups. In some cases errors increase, but they suggest different underlying reasons for the increase, while in others errors reflect the benefit of extra processing. Some possible reasons that could explain the effects of format group on representation and therefore on recall errors are outlined below.

The most important point to bear in mind is that in the MIT *all* texts in any format has matchtype structure, and that at an abstract level this information is always available, but the manner in which it is realised is dependent on a number of other factors. Thus, texts which have the same abstract information presented in different formats and/or modes cannot be assumed to result in identical representation structures. The temporal order in which it becomes available would have a major effect on how it is, or even can be, utilised for representational purposes. For example, it may result in higher processing loads but have no effect on the representation structures constructed to solve the binding problem, the extra predicted load, being due to other unresolved properties or some other aspect of the text.

Format can also determine whether the matchtype information becomes available on the first or the second presented individual. For example, in format group 2, matching status of dimensions becomes available equally often on each individual, which seems to have some influence on how matchtype information is utilised in the construction of representations. This raises a question about the interaction between individuals and their attributes. Recall error analysis gives some indication of such a confusion in texts presented in format group 2. This is also closely related to the effect of order of recall of individuals on errors during retrieval. As in other studies (eg, Stenning, Shepherd and Levy, 1989, and Stenning, Patel and Levy 1987), the second recalled individual is usually prone to more errors, which replicates previous findings reported in Chapter 4, where it is suggested that poor memory for the second recalled individual is a consequence of interference due to recall of the first recalled individual. Preliminary analysis of patterns in recall errors are presented to support a similar account of the effect of format group on representation structures.

1.2. Effect of MATLOAD-PLUS on errors

MATLOAD-PLUS provides us with an ideal opportunity to investigate differences in representation structures due to format group. The possibility that it represents processing due to a larger number of recruited associations in the representation has already been discussed in Chapter 5. If this is indeed the case, then on the basis that a reader is no longer reliant on redundancy but actively recruits associations between properties to guard against interference, one should be able to observe a different pattern of errors that reflect the predicted changes in her representation strategy. MATLOAD represents a process of assimilation of matching status, which is often reflected in higher than expected joint or polarity errors. Given that MATLOAD-PLUS is motivated on very different grounds, fewer joint errors would be expected because other unresolved properties can be better integrated with intra-individual associations. For the same reason higher multiple errors should occur since an individual's attributes would be closedly integrated in the representation. Both consequences are evident in the error patterns of the appropriate format.

2. Indirect models

For the present the main motivation for developing feature representation models was to identify any changes in representation structures due to format groups. Hence, models based on recall errors show significant differences in the saliency of selected semantic features for each format group. Collectively the findings of this study confirms that the role of information about matchtype structure is not independent of format, and therefore, temporal order of dimensions. This raises the question about differences in the saliency of representation features. In order to be able to address this issue it was decided to develop three separate models, one for each format group. They highlight some major differences that can be explained in terms of specific changes in subjects' representation strategies.

Interestingly the differences, at one level, are highly subtle, which hints at the complexity of the issue of text processing and knowledge representation. The models reveal the relative extent of the role of matchtype in each format group, but they also suggest that these changes cannot be explained in simple terms. Contrary to our expectations higher level semantic features associated with matching status were still selected by the representation models. It seems that, while text comprehension in some format groups requires more processing, and because of less robust representation strategies, recall is more prone to certain types of error, information about matchtype structure no matter how late its availability in a text, plays a significant role in determining a reader's representation of associations between properties. This gives an indication of the importance of form in determining the representation structures constructed during text comprehension, and also shows that while the role of matchtype information may be partly determined by the simpler format used in previous studies, it nevertheless has an independent role that is little affected by format or mode of MIT texts

All models are indirect since they are more illuminating as far as feature integration is concerned, which is of main interest since we expect format group to have an effect on the sorts of association recruited to bind intra-individual properties. Details about our methodological approach and motivation for using the present modelling techniques are given in Chapter 4, and therefore, not repeated here. Information on design and procedure of this part of the experimental study are given in the appropriate sections in Chapter 5. In the next section we present detailed analysis of mean recall errors by property, individual, format group and matchtype. This will be followed by analysis designed to seek out general patterns in recall errors which as we have seen in Chapter 4 can provide some interesting clues about the nature of underlying representation structures. Finally, we will present three separate indirect feature models and conclude with a brief discussion on the significance of the findings of this study.

3. Recall error results

3.1. Scoring method for recall error data

Recall was scored by the best-fit method, which is described in Chapter 4. Recall scores were assigned by giving one point for each correctly recalled property of individuals. This requires assigning recalled individuals (R-individuals) to presented individuals (S-individuals). Recall was not cued; subjects were free to recall individuals in either the presented order or its opposite. All analyses of recall errors presented here is based on order of recall which, as has been already noted, is the most significant determiner of errors.

Recall errors can be scored in terms of property dimensions, irrespective of their temporal position in texts. However, reading time results have shown that the Semantic Ordinal Effect is determined by the temporal order of properties of individuals, independent of their attribute dimensions. Preliminary analysis revealed that scoring by temporal order provided the best approach to our investigation of the effects of format group and matchtype structure on the representation of resolution to the binding problem in the MIT.

Matchtype structure is defined in terms of its availability, and not any abstract notion based on dimension order of S-individuals. However, this raises difficulties about assigning temporal position to the matching status of properties belonging to the same dimension but not presented in consecutive sentences. How do we label the first presented property? Consider a case in format group 2 where the second presented attribute of the first presented individual does not get resolved in terms of matching status till the fourth attribute of the second individual presented in the eighth (last) sentence. In strict temporal terms these two properties should be labelled B and D respectively but that would obscure the temporal position of matching status, which is definitely D. Since our main interest is in exploring and modelling the effect of higher level semantic information on representations it was decided to present the error data in terms of resolution of matching status. So in the above example of format group 2 the letter D, denotes the last dimension on which information about matching status became available, and thus it refers to both, the second presented property of S-individual 1 (given at sentence 3), and the fourth property of S-individual 2 (given at sentence 8). To summarise, properties A, B, C and D will refer to the temporal order in which their matching status become available in a text.

3.2. Preliminary results

Subjects recalled 71.41% (2054) of texts correctly. Overall mean unit of errors, 0.48 per text is considerably less than in the last study, (0.77 per text; see Table 2 in Chapter 4). This shows that text format in P x P mode has a less disruptive effect on recall than modes which give rise to unpredictable referential switches. Table 1 shows the mean unit of recall errors per text by format.

Table 1

Mean unit errors per text by format

Format:	1	2	3	4	5	6	7	8	9	All
Errors	0.37	0.55	0.57	0.54	0.41	0.56	0.53	0.55	0.44	0.48

3.3. ANOVA results

As for reading time analysis, separate ANOVA's on each format group were carried out to see if formats within format groups had a significant effect on recall errors. If this were the case then it would indicate that property dimension *per se* has an effect on the representation of a solution to the binding problem. For all three ANOVA's, subject is the random factor, and format (3 levels), matchtype (8 levels), R-individual (2 levels) and property attribute (4 levels) are fixed factors. There is no significant main effect of format within each format group. The F-ratios, **F** (2,38) = 0.53, **F** (2,38) = 0.10, and **F** (2,38) = 0.12, for format groups 1, 2 and 3 respectively, are not significant at $p < 0.05$. Unlike reading time data the ANOVA's for format groups 1 and 2 reveal some interactions between formats and other factors

In format group 1 there is a significant interaction between R-individual, format and matchtype (**F** (14,266) = 1.91, $p < 0.05$). Though overall there is some correlation between the number of mismatches and frequency of errors, this trend is not similar for all formats in this group. There does not seem to be a clear pattern that can explain this relatively weak interaction.

There is also an interaction between format, matchtype, R-individual and property (F = 1.44 $p < 0.05$). There is some indication that subjects are more likely to make fewer errors on the nationality dimension when it is mismatched, however, it is difficult to account for this since this phenomenon is not replicated in formats with others.

In format group 2, format interacts significantly with R-individual (F (2,38) = 3.53, $p < 0.05$). In all formats subjects make higher errors on R-individual 2 but this tendency varies between formats in this group. There is also an interaction between format, R-individual and property (F (6,114) = 2.43, $p < 0.05$). The reasons for these interactions are not obvious because the error patterns are not consistent with differences in dimension order of formats in this group.

In format group 3, format does not interact with any other factors. Significant interaction in the other two format groups indicate some effect of property dimension on recall errors but fail to reveal any error patterns that can be given an account in terms of differences in dimension orders within format groups. So recall data was collapsed across formats for the rest of the analysis. An ANOVA with subjects as the random factor, and format group (3 levels), matchtype (8 levels), R-individual (2 levels) and property attribute (4 levels) as fixed factors was carried out.

There is a main effect of format group (F (2,38) = 9.61, $p < 0.0005$). As in all previous studies subjects made fewest errors when recalling format group 1 texts. The mean unit errors per text for format groups 1, 2 and 3 are 0.44, 0.55 and 0.55 respectively. Texts in format groups 2 and 3 are equally difficult to recall.

There is a main effect of R-individual (F (1,19) = 25.9, $p < 0.0001$). Significantly more errors were made on R-individual 2. The mean unit errors are 0.20 and 0.28 for R-individual 1 and 2 respectively. This result corresponds with previous findings which suggest that recalling the first individual adversely affects recall of the second one, a conclusion supported by analysis of data by recall order presented below.

There is a main effect of matchtype (F (7,133) = 13.60, $p < 0.0001$). Mean unit errors were lowest for texts with all except property A matched. Table 2 gives the means for each matchtype pattern which shows the frequency of errors increases roughly in line with number of mismatches, a pattern observed in previous studies.

Table 2

Mean unit errors per text by matchtype structure

Matchtype:	+++	++-	+-+	+--	-++	-+-	--+	---	All
Errors	0.14	0.39	0.43	0.59	0.39	0.68	0.67	0.74	0.48

There is a main effect of property (F (3,57) = 8.74, $p < 0.0005$). As Table 3 shows, for both R-individuals subjects made the least number of errors on property A, and significantly more errors on properties B and C, which are closely correlated with the second and third presented properties of each individuals.

Table 3

Percentage of recall errors by property and by R-individual

	Property:	A	B	C	D
R-individual:	1	4.5	5.5	6.5	4.5
	2	4.9	8.5	8.6	7.4
Both R-individuals		4.7	7.0	7.5	5.9

The interaction between R-individual and property is highly significant, (F (3,57) = 5.30, $p < 0.005$). Overall subjects make more errors on all properties of the second R-individual, though the extent of the difference between properties B and D is larger than that between property C of individuals (see Table 3).

The interaction between matchtype and property is highly significant (F (21,399) = 2.77, $p < 0.0005$). As already noted subjects make a higher percentage of errors on mismatched property dimensions, indicated by an asterisk in Table 4. However, note the relatively high errors on matched property dimensions B an C in matchtype 4 and 6 respectively, which will be given further consideration later in this Chapter.

Table 4

Percentage recall errors on property by matchtype

	Property:	A	B	C	D
Matchtype:	1 (+++)	1.1*	1.9	2.1	1.9
	2 (++-)	5.8*	3.5	3.9	6.3*
	3 (+-+)	5.0*	4.9	9.5*	3.8
	4 (+--)	4.6*	7.9	10.1*	9.6*
	5 (-++)	4.4*	6.8*	3.5	2.8
	6 (-+-)	5.8*	9.7*	9.9	8.6*
	7 (--+)	4.8*	10.1*	10.1*	5.8
	8 (---)	5.8*	11.1*	11.1*	8.6*

The most interesting interaction is between format group and property (F (6,114) = 4.30, $p < 0.005$). Errors in format group 1 do not vary much between properties, as can be seen in Table 5, and format groups 2 and 3 make a larger contribution to overall errors on properties B and C. Format groups' effect on recall is not uniform across properties, which would be one expected consequence of differences in availability of matchtype information. Higher errors on properties B and C in format group 2 and property C in format group 3 could reflect confusion over individuals' properties due to the availability of matchtype information on S-individual 1. Further, higher than average errors on property

A in format group 2 supports this conjecture.

Table 5

Percentage errors on each property by format group

	Property:	A	B	C	D
Format Group:	1	4.1	5.3	4.9	5.8
	2	5.7	7.7	9.0	5.0
	3	4.2	8.0	8.7	6.9
All Formats		4.7	7.0	7.5	5.9

The interaction between format group, R-individual and matchtype is significant (F (14,266) = 1.85, $p < 0.05$), which is clearly due to lower errors in format group 1, and differences in errors between R-individuals. Table 6 gives the differences in percentage errors between matched and mismatched properties of each R-individual collapsed across matchtype and property.

Table 6

Percentage errors for matched and mismatched properties by format group and R-individual

		R-individual 1		R-individual 2	
		Match	Mismatch	Match	Mismatch
Format Group:	1	1.0	3.6	2.3	5.3
	2	1.3	6.2	3.4	7.3
	3	1.5	6.1	3.4	7.5

The interaction between R-individual, property and matchtype is significant (F (21,399) = 1.89, $p < 0.05$). Table 7 shows the percentage errors by matched and mismatched properties of each R-individual. The interaction is due to the overall difference in matched and mismatched properties, together with the consistently lower than average errors on property D, which is likely to be a recency effect. Together, Tables 6 and 7 illustrate that it is format group, and not temporal position of properties which is the main determinant of errors on matched and mimatched property dimensions.

Table 7

Total percentage errors on matched and mismatched properties by property and R-individual

		R-individual 1		R-individual 2	
		Match	Mismatch	Match	Mismatch
Property:	A	-	4.5	-	4.9
	B	1.2	4.2	3.3	5.2
	C	1.6	4.9	3.3	5.3
	D	1.0	3.4	2.5	4.9

3.4. Recall order ANOVA results

Before discussing the above findings, we first present analysis of recall errors in terms of recall order. Subjects recalled individuals either in the order presented or its reverse. These two orders will be referred to as recall orders 1 and 2 respectively. Of all texts, 1,782 (62.0%) were recalled in recall order 1 and 1,094 (38.0%) in recall order 2.

To see if recall order was significantly affected by format group (3 levels) or matchtype (8 levels) an ANOVA was carried out with subjects as a random factor. Recall order was the dependent variable with the data collapsed across R-individual and property. There is a significant main effect of matchtype ($F\ (7,133) = 2.89$, $p < 0.01$). Texts in matchtype patterns 1 and 2 are more likely to be recalled in recall order 2 as can be seen in Table 8. This suggests that individuals with a higher number of matched properties, particularly those presented in the early part of texts, share similar fates in memory in terms of primary/secondary status in the representation. They are both equally likely to be recalled in either order. This strategy is not affected by format as there is no significant main effect of format group or any significant interaction between format group and matchtype.

Table 8

Percentage of texts recalled in each recall order by matchtype

	Matchtype:	+++	++-	+-+	+--	-++	-+-	--+	---
Recall Order:	1	51.8	59.2	65.3	64.2	64.7	61.4	65.0	63.6
	2	48.2	40.8	34.7	35.8	35.3	38.6	35.0	36.4

To investigate the effect of recall order on errors, an ANOVA was carried out with subject as a random factor and matchtype (8 levels), format group (3 levels), R-individual (2 levels) and property attribute (4 levels) as fixed factors. As in the main ANOVA, there are significant main effects of format group, matchtype, property and R-individual. Here, we will only report findings relevant to the effect of format and matchtype on recall order and errors.

There is a significant main effect of recall order (**F** (2,19) = 25.56, $p < 0.0005$). Subjects made significantly more errors on texts recalled in recall order 1 (0.58 and 0.39 mean units of errors per text for recall orders 1 and 2 respectively). This reflects the fact that texts with higher number of matched dimensions, which make up a larger proportion of those recalled in recall order 2, are prone to fewer recall errors.

The only relevant significant interaction is between matchtype, property and recall order (**F** (21,399) = 1.89, $p < 0.05$). The reason for this interaction is unclear as the distribution of percentage errors by matched and mismatched properties shows in Table 9.

Though subjects are less likely to make errors on properties recalled in recall order 2 this trend is not consistent, matched property C and mismatched property D being notable exceptions.

Table 9

Percentage errors on matched and mismatched properties by recall order

	Property:	A match	A mis	B match	B mis	C match	C mis	D match	D mis
Recall Order:	1	-	12.4	5.1	10.1	4.8	12.5	4.3	8.3
	2	-	4.4	3.6	8.5	5.0	6.4	2.3	8.2

In both recall orders subjects make more errors on R-individual 2 than on R-individual 1. The difference in errors between R-individuals is 2.4% and 1.9% for texts recalled in recall order 1 and 2 respectively. This indicates that the disruptive effect of recalling the first individual on recall of the second individual is not significantly affected by recall order. There is no interaction between recall order and format group. The tendency for a higher percentage of errors on texts in format groups 2 and 3 is similar for both recall orders.

3.4.1. Discussion of ANOVA findings

Subjects make higher errors when recalling texts in format groups 2 and 3 than format group 1, and this effect reflects differences in availability of matchtype information. Higher errors on R-individual 2 were also observed in all format groups, which is consistent with the finding of the first study, and is due to interference resulting from retrieval of R-individual 1.

There are two possible effects of matchtype on recall errors due to format group. The first one is the effect of availability of matching status information on different S-individuals. This effect is most obvious in format group 2 where subjects learn about the matching status of half the dimensions on S-individual 1. This results in a higher frequency of recall errors which suggests some sort of confusion over intra-individual bindings of property attributes of individuals. Subjects may know the matching status of a property dimension but fail to assign the attributes to the appropriate individual.

The other effect is the delay in the availability of information about matchtype structure and the simultaneous load of unresolved properties. This effect is strongest in format group 3 which, suggests that lack of ready availability of matchtype information has an adverse effect on subjects representation strategy to solve the binding problem. We will return to this at the end of this Chapter.

Apart from above, the main effects of matchtype are similar to those observed in the previous study. Subjects tend to make more errors on mismatched properties, and on R-individual 2. Recall order analysis confirms that this effect is mostly due to interference resulting from recall of the first individual. A bias for recalling individuals with more than two matched properties in recall order 2 is also observed indicating that matched attributes are probably not as highly integrated in the representation as mismatched ones; subjects are relying on redundant information and not on intra-individual associations, which compliments the relatively low processing associated with MATLOAD in Model 3.

3.5. Property-oriented analysis

The following analysis was carried out to investigate the effect of format groups on recall error patterns. More specifically we are interested in looking at the frequency of single, joint and multiple errors which give an indication of the relative integration of individuals' attributes in the representation. This analysis also provides a general idea of differences in representation structures due to format group. First, the analysis of recall errors on properties between individuals is reported, which provides a clearer picture of the role of matching status of property dimensions in the representation.

Table 10 shows the distribution of single errors (on either R-individual 1 or 2) and joint errors (on both individuals on the same dimension) for each property of R-individuals by format group. We assume that joint errors reflect inter-individual links based on matching status of property dimensions. If inter-individual associations have been recruited then failure to recall correctly one individual's property is likely to lead to failure to recall other individual's property on that dimension. While previous findings support the plausibility of this assumption it is not obvious from the observed error patterns that *all* joint errors reflect these sorts of underlying association encoded in the representation. Since, in format groups 2 and 3, individuals are presented in unidentical dimension orders which affects information about matching status, fewer joint errors would be expected which in comparison to the large difference in single errors between format group 1 on the one hand, and format group 2 and 3 on the other, seems to be the case.

Compared to format group 1, single errors in format group 3 are significantly higher, but the frequency distribution of joint errors is remarkably similar which does suggest a diminished correlation between properties in this format group. However, in format group 2 higher joint errors suggest a more enhanced role of matchtype information in the construction of the representation. These two different patterns of joint errors can be explained in two ways. First, texts in format group 2 only really disrupt information about the matching status of property D, which has the lowest percentage of joint errors (1.6%). On the other hand, higher joint errors on properties A, B and C could reflect the confusion between individuals that was referred to in the previous section, and therefore, is likely to be due to interference during retrieval. A higher occurrence of joint errors on property A (5%), the introducer, lends support to this explanation.

Table 10

Percentage single and joint errors on properties by R-individuals

	Property:	A	B	C	D
Format group 1					
	R-individual 1	0.7	1.3	1.8	1.7
	R-individual 2	1.0	3.3	3.2	4.0
	Both R-individuals	3.2	3.0	2.4	3.0
Format group 2					
	R-individual 1	0.5	2.7	2.9	1.7
	R-individual 2	0.9	5.0	6.6	5.0
	Both R-individuals	5.0	3.9	4.3	1.6
Format group 3					
	R-individual 1	0.3	2.5	4.2	3.0
	R-individual 2	0.9	7.4	5.4	6.1
	Both R-individuals	3.6	3.0	3.9	2.4

Next, consider the distribution of joint errors in terms of their matching status given in Table 11. In line with previous findings, subjects make more joint errors on mismatched property dimensions than on matched ones. The highest frequency of joint errors is occurs on mismatched properties B and C in format group 2, and property C in format group 3 (3.1%, 3.2% and 3.8% respectively), which also happens to be the property dimensions where information about matching status is available on S-individual 1.

Table 11

Percentage joint errors on matched and mismatched properties by format group

	Property:	A mat	A mis	B mat	B mis	C mat	C mis	D mat	D mis
Format group:	1	-	3.2	0.6	2.4	0.6	1.8	0.5	2.5
	2	-	5.0	0.7	3.1	1.0	3.2	0.1	1.5
	3	-	3.6	0.1	2.9	0.1	3.8	0.4	2.0

The most interesting result is the remarkably low occurrence of matched joint errors on property D in format group 2 and property B and C in format group 3. As predicted by reading time Model 3, if subjects are spending more processing on these matched properties, to avoid interference due to semantic or acoustic similarity, then such a pattern of low errors would be expected. This result supports the motivation of the variable, MATLOAD-PLUS, and our account of the sorts of cognitive processes it represents.

3.6. Individual-oriented analysis

In this section we present analysis of errors within individuals, which provide an indication of shared fates of properties of each individual in memory. This analysis looks at the pattern of discrepancies between a R-individual and its target S-individual. For any R-individual subjects can either make an error on one property or they can make a combination of errors on two or more properties. Frequency of multiple errors gives an indication of the extent to which intra-individual association are recruited to bind properties of individuals.

Table 12 shows that single and multiple errors on R-individual 2 are more likely than on R-individual 1, and both sorts of errors are generally more frequent on the individuals presented in format groups 2 and 3. It also gives an indication of the degree to which an error on any one property is likely to be correlated with other properties of the same R-individual. The highest percentage of multiple errors occur on R-individual 2 in format group 3, which have a tendency to include property B and C. To a lesser extent this is also the case for R-individual 2 in format group 2. Both indicate a relatively high incidence of intra-individual associations predicted by reading time Model 3.

Table 12

Percentage of single and multiple errors on each property by
R-individual
and format group

		Single errors				Multiple errors			
	Property:	A	B	C	D	A	B	C	D
R-individual 1									
Format Group:	1	3.2	3.1	3.5	4.2	0.7	1.2	0.7	0.5
	2	4.2	4.3	5.4	2.2	1.4	2.2	1.9	0.7
	3	3.0	3.7	5.7	3.9	0.8	1.9	2.3	1.6
All Formats		3.5	3.7	4.8	3.4	1.00	1.8	1.6	0.9
R-individual 2									
Format Group:	1	3.6	4.5	3.8	5.4	0.7	2.0	1.9	1.6
	2	4.1	5.5	7.8	3.8	1.9	3.3	3.0	2.9
	3	3.2	6.1	5.7	5.0	1.3	4.7	3.6	1.7
All Formats		3.6	5.4	5.8	4.7	1.3	3.2	2.8	2.1

3.7. Log-linear analysis

Log-linear modelling (see Bishop, Fienberg & Holland, 1974) of errors based on separate consideration of data from R-individual 1 and 2 gave us models of the relation between errors on properties of each R-individual. It revealed highly integrated models for the total scores collapsed across format group (see Table 13). The introducer of R-individual 2 is not involved in multiple errors, but the other three properties seem to share a common fate in memory, though this partly reflects interference during recall. The overall model for R-individual 1 properties is notable for the unexpected correlation between property A and B, which also shares a common fate with all other properties.

Models for each format group reveal similar differences in correlation between errors on properties of R-individuals. They show that the pattern of involvement of various properties in multiple errors is determined by the temporal order of presented properties rather than their property dimension. This is particularly clear in models of R-individual 2 where property D's involvement in multiple errors replicated findings of the first study. However, models of R-individual 1 in all formats reveal some interesting correlation. The model in format group 1 is the least integrated of all three models, and the correlation between properties A and B is unexpected. Unlike previous results the last presented property is not always the one most often involved in multiple errors, instead property B seems to share its fate with other properties most often.

Table 13

Hierarchical log-linear models of within R-individual error data by format

		R-individual 1				R-individual 2			
		Model	X^2	DF	prob.	Model	X^2	DF	pro
All Formats:		AB, BC, BD, CD.	6.56	7	p=0.48	BCD, A.	9.62	7	p=0.
Format group:	1	AB, BC, D.	5.71	9	p=0.77	CB, CD, A	5.81	9	p=0.
	2	AB, BC, BD, CD	7.46	7	p=0.38	BD, CD, A	12.56	9	p=0.
	3	BC, BD, CD, A	5.72	8	p=0.68	BCD, A	5.36	7	p=0.

3.8. Discussion of property- and individual-oriented analyses

To summarise, the foregoing analyses has revealed a number of wide ranging effects of format group on subjects' representation strategies for solving the binding problem in the MIT. The main finding is that availability of information about matchtype structure has a major effect on the sorts of association recruited. These are particularly salient for representation structures of texts presented in format groups 2 and 3.

It seems that resolution of matching status on S-individual 1 has an adverse effect during recall. The most likely explanation for this is that it leads to a higher incidence of confusion between properties of each individual, as suggesting the pattern of joint errors in format group 2. At this stage, the exact nature of the role of matchtype information is unclear, though the results show that it does have an effect on the sorts of representational structures that are constructed.

The other main finding is that a lack of matchtype information in the early part of a text has a major influence on representation strategies. This effect is most clear in the observed patterns of error in format group 3. There are two aspects to this. First, the notable low frequency of joint errors on matched property errors which concurs with the prediction based on MATLOAD-PLUS processing variable selected by Model 3, and second, the greater degree of integration of attributes of each individual in the representation structures which agrees with the results of log-linear analysis. However, this does not necessarily suggest that the role of information about matchtype structure is significantly diminished, since it is obvious from the reading time model that subjects are aware of higher level semantic information during the construction of representations. What it could mean is that the role of matching status as a source of *redundant* information is much reduced because it is not as readily available as it is in format group 1, and, as it was in the previous study. The relatively high frequency of single errors in format groups 2 and 3 tends to support this account. The shift in representation strategy is reflected in the pattern of multiple errors and log-linear analyses which indicates greater reliance on intra-individual links to solve the binding problem. This explanation is more plausible since it would be unlikely that higher level information about the relational structure plays no role in the resolution of the binding problem.

4. Development of indirect models

In this section we report further analysis of the recall errors in terms of more complex error types defined in terms of matchtype structures. The classification of error types and the development of integrated models of recall performance are motivated on the same grounds as the ones for the previous study. Full details of these are given in Chapter 4. Representational feature models will enable us to gain a better understanding of the underlying representation structures that provide the best explanations for the observed differences in error patterns of each format group, and they also predict some of the differences in representations anticipated on the bases of findings reported above.

4.1. A classification of error types

The classification of error types is the same as the one used in the analysis of recall data of the first experiment. These include single unit errors which always alter the matching status of the property dimension, and double errors or polarity errors which occur simultaneously on one property dimension and do not disturb their matching status. There are two types of polarity errors; *property polarity* errors refer to two errors on matched properties, and *individual polarity* errors refer to two errors on mismatched properties. Errors on different dimensions are classified as *double homogeneous* (both match to mismatch or both mismatch to match) or *double complementary* (one of each). These two error types can occur on either R-individual 1 or on R-individual 2 or one on each individual. Table 14, which is identical to Table 8 in Chapter 4, gives a few examples of the basic response types.

Polarity errors can occur in multiples; two individual polarity, two property polarity, or mixed polarity. Matching status errors can occur with polarity errors in a large number of combinations. Finally, most possible error types fall into none of these categories, but also hold little obvious theoretical interest, and therefore as before are consigned to a miscellaneous response type.

Table 14

Some examples of recall error types

Response Type	Response							
Correct	tall	happy	Polish	bishop	short	happy	Swiss	dentist
Single	**short**	happy	Polish	bishop	short	happy	Swiss	dentist
Individual Polarity	**short**	happy	Polish	bishop	**tall**	happy	Swiss	dentist
Property Polarity	tall	**sad**	Polish	bishop	short	**sad**	Swiss	dentist
Double Complementary	tall	**sad**	Polish	bishop	short	happy	**Polish**	dentist
Double Homogeneous	**short**	happy	**Swiss**	bishop	short	happy	Swiss	denti

4.2. Observed recall error types

Apart from one correct response there are a number of ways in which other response types can be made, and the subset of error types vary according to paragraphs with different matchtypes. The proportion of all responses, separated by format groups, falling into each of the twenty response types are shown in Table 15, together with the proportion of all possible responses of random recall falling in that response type averaged over all matchtype structures. The error types chosen are the maximal set of those listed above which were sufficiently represented in the data. Their abbreviations are spelt out for reference.

Table 15

Observed and possible probabilities of occurrence of response types

Abbreviation	Response Type	Observed				Possible
		Format Group			All Formats	(all formats)
		1	2	3		
corr	Correct	.763	.697	.684	.714	.006
misc	Miscellaneous errors	.009	.017	.011	.013	.596
sg1+	Single error on r-1 matched	.017	.024	.023	.021	.009
sg1-	Single error on r-1 mismatched	.027	.026	.036	.030	.015
sg2+	Single error on r-2 matched	.022	.028	.041	.030	.009
sg2-	Single error on r-2 mismatched	.045	.052	.041	.046	.015
ipol	Individual polarity error	.070	.077	.074	.074	.015
is1+	Individual polarity with "sg1+"	.004	.007	.004	.005	.016
is1-	Individual polarity with "sg1-"	.003	.007	.009	.007	.023
is2+	Individual polarity with "sg2+"	.006	.015	.010	.010	.016
is2-	Individual polarity with "sg2-"	.003	.005	.008	.006	.023
2cs1	Double complementary both on r-1	.002	.004	.007	.005	.019
2cs2	Double complementary both on r-2	.003	.006	.014	.008	.019
2cdf	Double complementary on r-1 & r-2	.004	.007	.011	.008	.032
dhs1	Double homogeneous on r-1	.002	.004	.005	.004	.019
dhs2	Double homogeneous on r-2	.000	.004	.007	.004	.019
dhdf	Double homogeneous on r-1 and r-2	.002	.002	.004	.003	.037
ppol	Property polarity error	.014	.010	.003	.009	.009
pp+s	Property polarity with single	.002	.003	.002	.003	.055
mirr	Mirror image matchtype structure	.001	.003	.004	.003	.049

Similar to the findings of the last study, for all three format groups possible probability of correct response in grossly underpredicted, while the number of observed error types subsumed under miscellaneous is a lot lower than predicted. Overall single errors are more common than possible though they are not as high as those observed in the previous study which reflects the generally lower frequency of errors associated with texts in P x P mode. R-individual 2 in format group 2 has the highest single errors on mismatched properties. However, the most interesting result is that in format group 3 the occurrence of responses with single errors on R-individual 2 is the same (0.041) for matched and mismatched properties. To a lesser extent this is also the case for R-individual 1 in format group 2. This indicates that in these two formats redundant information about matching status plays a less significant role, as predicted by the reading time model. The low frequency of property polarity errors in format group 3 (0.003 against the possible proportion of 0.009, which is exceeded in the other two format groups) supports this account.

As in the first study, individual polarity errors occur more frequently than expected, and is on average higher in this study; 0.074 for all formats compared to 0.067 in the previous study. The apparent difference between the two studies is greater if we take into account the overall lower frequency of errors in the present study, of which individual polarity errors make up a larger proportion. This bias in response type may reflect the effect of confusion between properties of individuals; the observed frequencies, 0.070, 0.077 and 0.074 for format groups 1, 2 and 3 respectively, provides some support for this account.

While there is roughly an equal opportunity to make a double complimentary or a double homogeneous errors (0.070 and 0.075 respectively), the former are twice as common as the latter (0.021 and 0.011 respectively). Both SSL and our first study show similar trends. The difference between these two response types hold for each format group, but the observed frequency varies; format group 3 has the highest errors of both kinds, followed by format groups 2 and 1. This suggests that in format group 3 subjects may have difficulties in remembering the 'odd-man-out' dimension, that is, the matching status of the dimension which is dissimilar to the other two - all matchtype structure patterns except 1 (+++) and 8 (---) have this characteristic.

Overall, this analysis of recall errors shows that to some extent the distribution of response types is different for each format group, which indicates that the representation of the resolution of the binding problem is affected by the sequence of presentation of dimension order of individuals, and therefore, the availability of information about matchtype structures. This is the main reason for carrying out separate regression modelling analysis to predict the sets of features which account for the observed distribution of response types for each format group.

4.3. Indirect models of representation features and discussion

Indirect regression models for the error frequencies were derived in the same way as the models presented in Chapter 4, using the same candidate features and the same error types. The independent variables were the features which provide a measure of similarity between stimulus and response based on the feature value that they share. Each feature identified a variable whose value for a response type was the proportion of times its proposition had the same truth value when applied to both stimulus and response. Thus for a completely correctly recalled paragraph, all features have a value of 1, since anything true of the stimulus is also true of the response, and anything false of the stimulus is false of the response.

The dependent variable is a measure of the frequencies of error types adjusted by the proportional probability of opportunities for making errors of each type. This adjusted frequency was then logged to give us a nearly normal distribution of response type frequency. As explained in detail in Chapter 4, this analysis gives us a model of the relative importance of semantic features which predict the observed error types, and thus, the extent to which different sorts of representational structures are involved in the solution of the binding problem in human memory.

Before reporting the results of the stepwise multiple regression analysis, we repeat a summary of features offered as independent variables:

(1) Features integrating attributes of either individual are included. The population of such features generated consisted of the features made up of all consistent subsets of <*A*, ˜*A*, *B*, ˜*B*, *C*, ˜*C*, *D*, ˜*D*> ranging from *A* to *There were eighty such features in all.*

(2) Features integrating the property attributes across dimensions, representing matchtype information, are also included. There are four of these, DIMAMAT, DIMBMAT, DIMCMAT and DIMDMAT. Each is identified by a proposition of the form: $xy(Fx \ \& \ {}^{-}Fy)$ where F is the predicate identifying the relevant dimension.

(3) NMAT is a meta-matching feature. As in the direct model it was defined in terms of the number of matched dimensions in a text.

For reasons given above, separate models for each format group were developed using the P2R Stepwise Regression routine of the BMDP statistical package (Dixon et al, 1968, 1983). For each format group, a model was fitted to the error data scored in R-orientation. Each feature variable is assigned a coefficient which is interpreted as the degree of salience of a particular feature in determining the similarity of stimulus and response. The three models are summarised in Table 16. The contribution of each variable to $\mathbf{R}^2$ is significant. Each includes a set of feature variables which are the best predictors of recall performance. The goodness-of-fit of the predicted models are illustrated in the Histograms comparing observed error types with those predicted by the models in Figures 1, 2 and 3.

Table 16

Summary of indirect models predicting error frequencies from feature scores

Format Group 1 $R^2 = 0.90$ df. = 15/62			Format Group 2 $R^2 = 0.90$ df. =13/79		
Feature	Coefficient	Standard Error	Feature	Coefficient	Standard Error
Intercept	-5.73		Intercept	-5.92	
			NMAT	0.20	0.07
DIMAMAT	0.41	0.18			
DIMBMAT	0.76	0.11			
DIMCMAT	0.45	0.11	DIMCMAT	0.71	0.08
DIMDMAT	0.40	0.15			
A	0.63	0.28	A	1.36	0.18
D	0.56	0.16	B	0.57	0.10
BA	0.49	0.11	D	0.82	0.10
B˜A	0.66	0.13	B˜A	0.51	0.10
C˜A	0.49	0.11	DB	0.28	0.10
DCA	0.51	0.13	˜C˜B˜A	0.46	0.09
D˜CA	0.42	0.11	D˜CA	0.51	0.10

Format Group 3 $R^2 = 0.88$ df. = 13/84		
Intercept	-4.30	
NMAT	0.23	0.07
DIMAMAT		
DIMBMAT	0.29	0.08
DIMCMAT	0.67	0.08
DIMDMAT	0.32	0.10
A	0.56	0.18
B˜A	0.74	0.10
D˜B˜A	0.29	0.11
DC˜A	0.40	0.11

Figure 1: Observed and predicted response type of format group 1

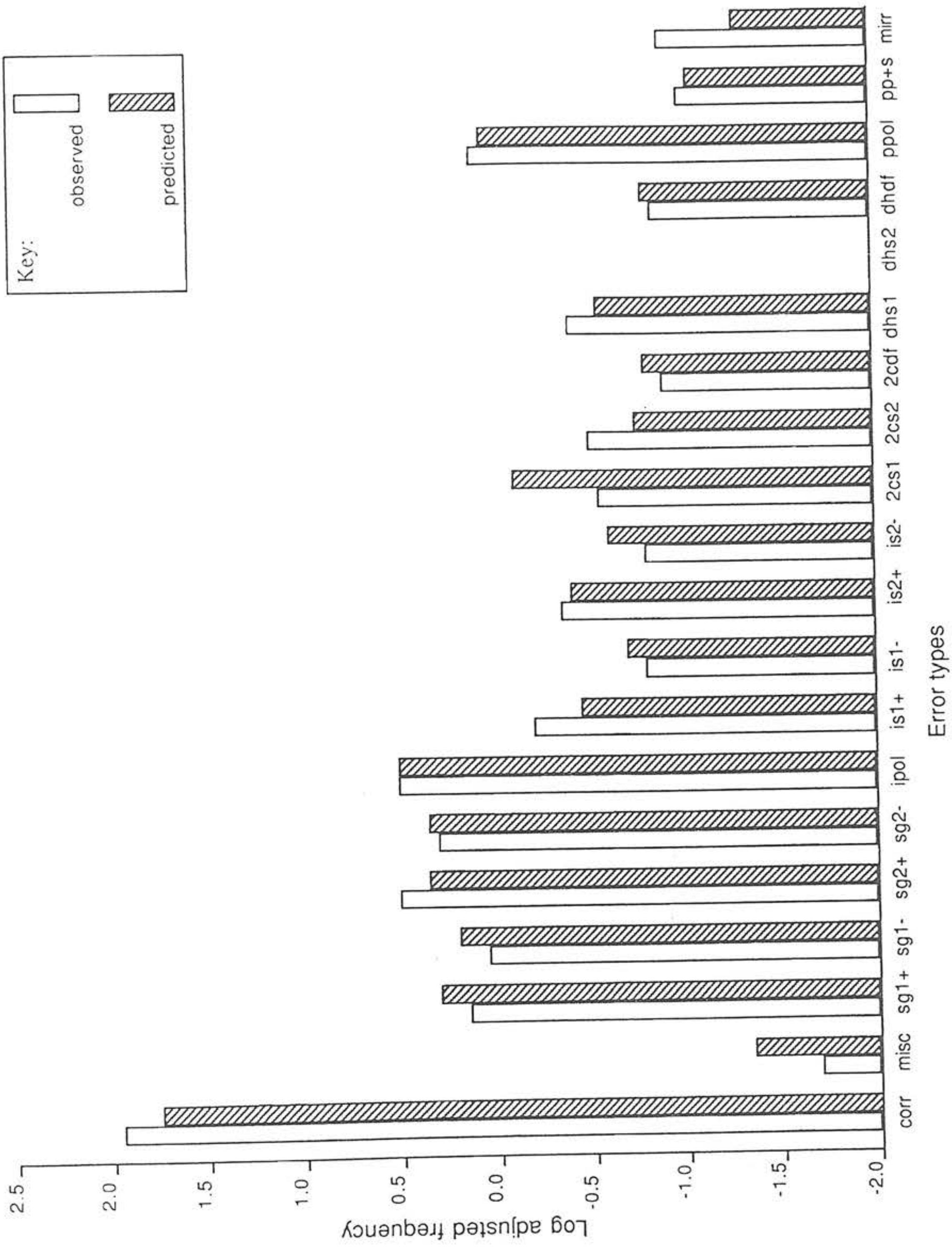


Figure 2: Observed and predicted response type of format group 2

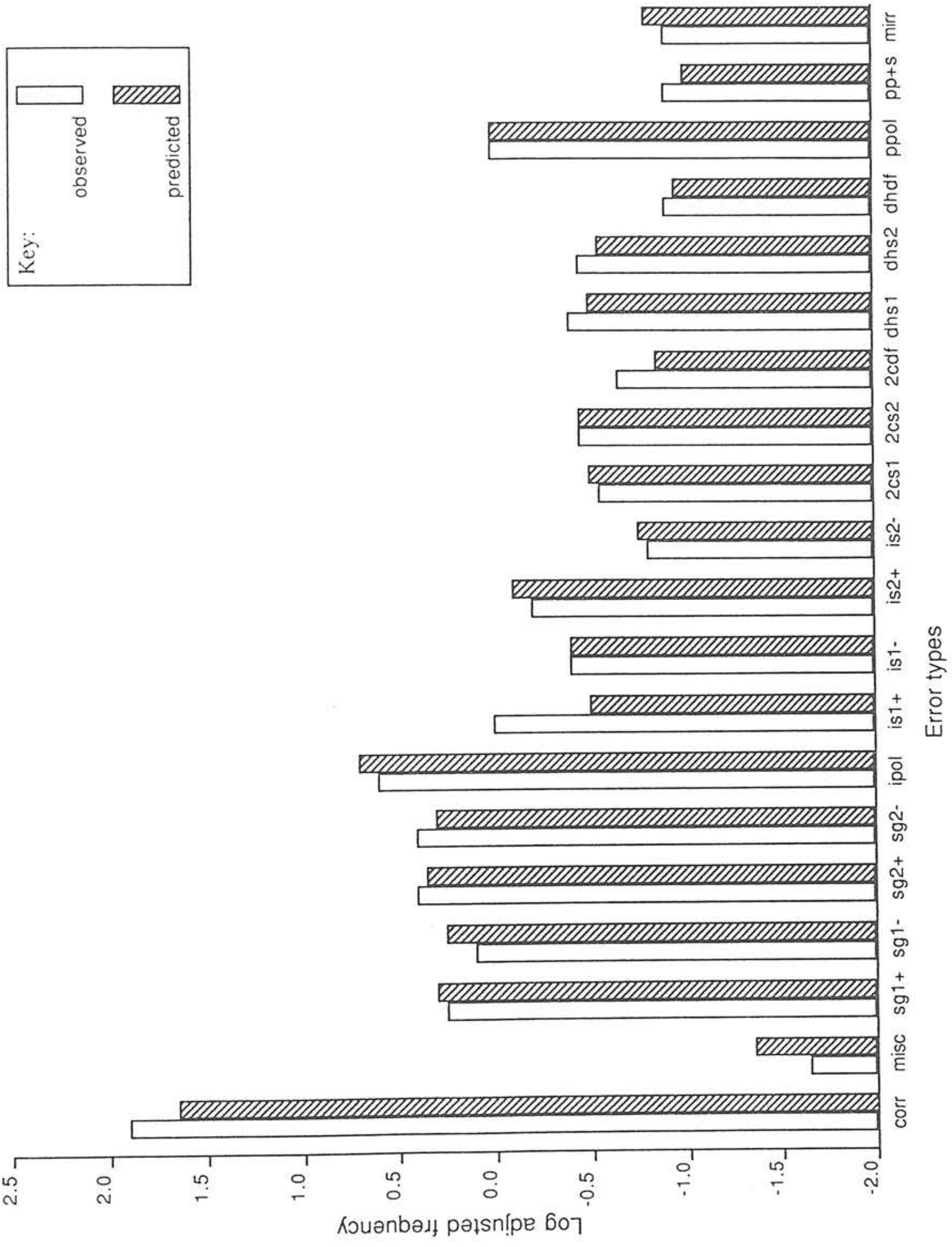
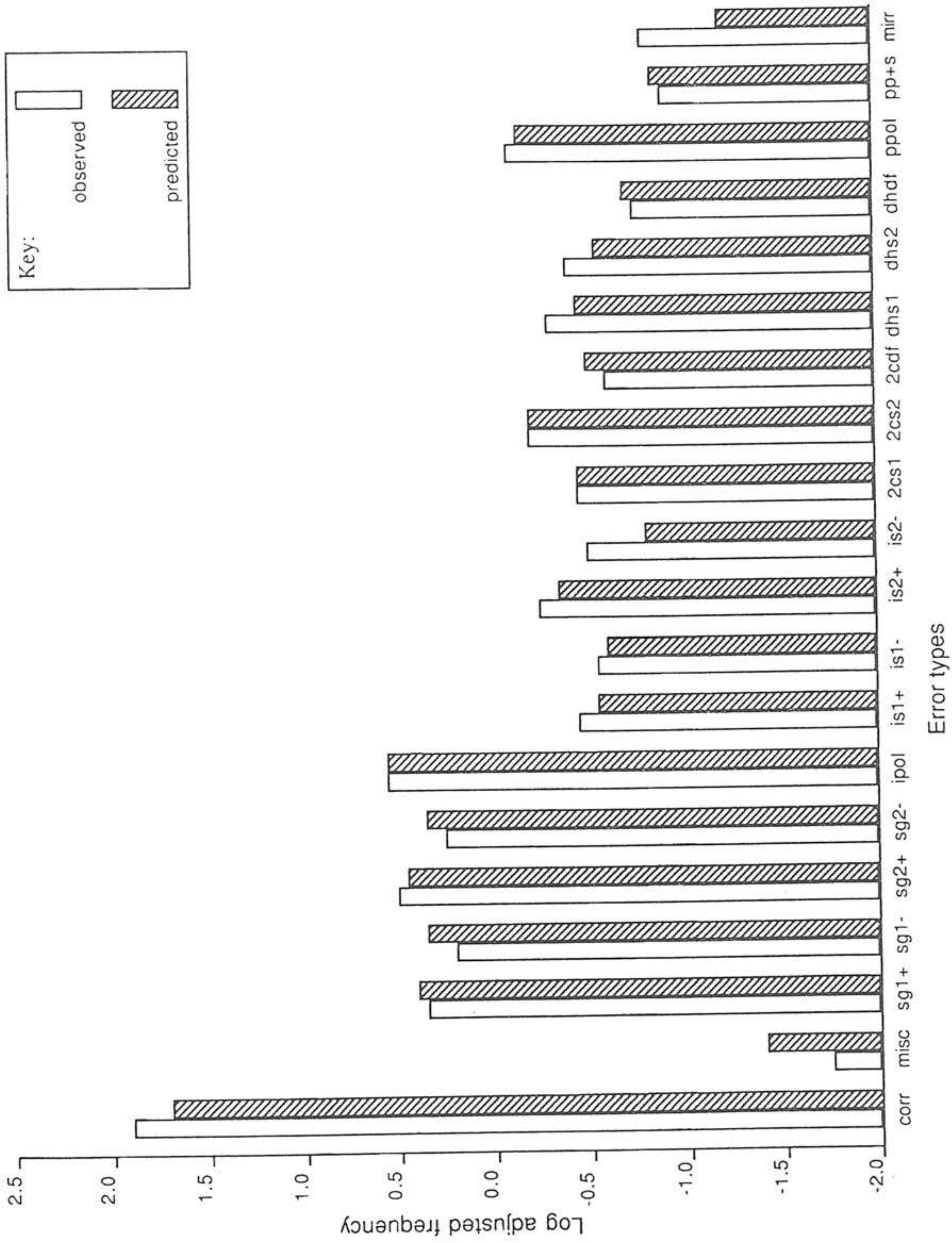


Figure 3: Observed and predicted response type of format group 3



Larger features selected by indirect models do not predict more multiple errors but give an indication of the degree of integration in the representations. The difference in the number of multiple features reveal differences in the effect of matchtype information. Format group 3 model includes four ternary and one fourary features. It also has the lowest number of single and binary features. Both these aspects of the indirect features model suggest a high degree of intra-individual integration in the representation, which is consistent with our predictions based on the findings reported above. None of the ternary features are consistent with the fourary feature, which indicates that subjects are relying on large features to make inferences about properties of individuals. It also selected NMAT and all except DIMAMAT higher level feature variables. This is contrary to our expectations based on preceding analyses which indicated that the sort of semantic information represented by higher order variables is not encoded in the representations. We return to this below.

For format group 2 only NMAT and DIMCMAT are selected by the model. On the face of it this suggests that matchtype information plays a diminished role in the representional structures in this format group. This outcome needs to be considered in tandem with other features selected by the model. There are four single intra-individual features and no fourary features, which reveal two things about the nature of the representation structures. First, bearing in mind that single properties could not help to resolve individuals, the model predicts some confusion between individuals. Second, the selection of these features suggests a more fragmented representation of individuals. None of the binary features are consistent with the ternary features, all of which include the third property dimension, C, which seems to play a central role in the organisation of the representation in this format group.

This raises the question about whether the confusion occurs in the representation or during recall. Since MIT texts are made up of very simple declarative sentences it seems highly unlikely that the confusion would occur during the construction of the representation, indeed the predicted loads of construction processes do not give any obvious indication of this. Further, information about matchtype structure in this format group is a lot more readily available than it is in format group 3, the recall model of which, predicts a high degree of integration in the representation. On the other hand, text format in this group is more prone to confusion during recall as explained above. Finally, the selection of NMAT shows that recall errors in this format group reflect the distinction between double complementary and double homogeneous errors, which in turn suggests that this sort of higher level information about the number of matched and mismatched dimensions is encoded. If this were the case it would support our account that the observed error patterns reflect confusion during recall.

In terms of availability of matchtype information format group 1 is very similar to format group 2, but the model predicts very different sorts of features. All higher level features except NMAT are selected which indicates the importance of this information in the organisation of the representational structure. The selection of single features, D and ~D suggests that the final property is sometimes not as well integrated as the other properties. Clearly a case of readers' reliance on the recency effect. None of the ternary features include the second property dimension, B (or ~B), while, three out of the four binary features include that dimension. The reason for this is not very clear though the pattern suggests that the representation of the second property is closely linked with the introducer, something which was not in evidence in the previous study. This may be an effect of the experimental task, which enabled subjects to be able to predict the format of a text only after the second properties of both individuals had been introduced (at sentence four).

The selection of all higher level features except DIMAMAT by the format group 3 model indicates the unexpected saliency of these underlying features accounting for the observed patterns of recall errors. While these are very different from the ones observed in format group 1, the model predicts a comparably important role of information about matching status of property dimension. Does this show that though matchtype information is not as readily available or accessible in format group 3, it nevertheless plays a major role in the construction of representations? If this were true, it would be difficult to reconcile it with the obvious differences in the observed error patterns reported in previous sections. One plausible account that can resolve this contradiction is that the role of matchtype information may be slightly different in each format group. The representation structures in format group 1 may reflect matchtype as redundant information, while in format group 3 it is probably an outcome of the more integrated and complex representations of bindings between properties.

A good example of this phenomenon is our account for the sort of processing represented by MATLOAD-PLUS, where it was argued that subjects are indeed aware of matching status but not encoding it as redundant information. It is possible that the each model's selection of higher level features is motivated on different grounds, and that in format group 3 the features reflect an emergent property of the representation structures that is not immediately obvious from less fine grained analysis of observed patterns of recall error. At this stage this account will have to suffice till a more appropriate study is carried out to investigate in greater detail the effects of differences in the saliency of matchtype information in the constructed representation of a solution to the binding problem in MIT texts. However, the present study has shown beyond any doubt that the role of matchtype information is determined largely by the temporal order of its availability; texts which at an abstract level contain the same sort and amount of information about individuals' property attributes and higher level semantic structure still obtain radically different representation structures in human memory. This is the most important finding of this study.

5. Concluding remarks

The results of this study confirms that while general knowledge plays a major role in recruiting associations to solve the binding problem the temporal sequence of content, *per se*, has no effect on working memory processes or long term representations. Temporal order, however does have an indirect effect on working memory implementations, because it affects the order of higher level semantic information. On the basis of these findings it is clear that some of this effect can be accounted for by the potential for confusion due to matching properties. Whether, this is due to acoustic or semantic similarity cannot be determined from the present study. Though, in light of the high likelihood of an interaction between rehearsal and semantic processes in working memory suggested by the findings of the first study it would not be surprising that the extra processing associated with certain properties presented in particular temporal orders was due to both these factors. Nevertheless, it is undoubtedly clear that processes in working memory are sensitive to the presentation order of higher level semantic information of MIT texts, and more to the point this provides a partial answer to the question about whether matchtype information is confined in its implementation to working memory, which was raised in Chapter 4. The Semantic Ordinal Effect represents processes associated with temporal aspects of the texts, and is independent of the dimensional order. This we take as further support in our approach which concentrates on investigating text processing in human memory in terms of higher level semantic structures of MIT text.

There is no indication that the representation of MIT texts is not organised around individuals and their properties. On the other hand, it is evident from the indirect representation features models that working memory processes do have an effect on the structures employed to solve the binding problem. The order in which information about matches and mismatches is presented has a significant effect on the organisation of representations, though the central role of this sort of higher level information in supporting elaborate representation structures to solve the binding problem in MIT is not diminished. Our analyses of recall errors show that the extent to which this information affects the underlying long term representations is determined by the temporal order of its availability. But it also shows that when it is delayed it does not cease to be important in long term memory implimentations, but it does lead to different sorts of representation features being constructed. These differences enable us to draw an important distinction on the role of matchtype information in representation strategies: it seems that such information is sometimes used as a source of redundancy, but most of the time it is integrated as part of the associations recruited to reprepresent individuals and their properties. The representation feature models of format groups 2 and 3 support this conclusion, as we have shown in the previous section.

Chapter 7

1. Concluding remarks

As outlined in Chapter 1 the results of both studies have shown how solutions to the binding problem in a typical Memory for Individuals Task provide interesting insights into cognitive processes involved in text comprehension. The findings have confirmed the initial conclusions drawn by Stenning Shepherd and Levy (1988), that is, the Semantic Ordinal Effect is a general phenomenon which reflects underlying cognitive processes. Our explanation of these processes in terms of readers establishing associations between parts of the semantic structures which they are reading about (in order to solve the binding problem) has been upheld. That part of the variance in reading times which is controlled by structural considerations can be accounted for rather accurately by simple linear models which show how the processes are organised around what is known about the currently referenced individual. We interpret these times as chiefly taken up by recruiting associations from long term memory which serve to implement the associations required by the structures presented. The parts of the structures which are thus tied together are exhibited in the models of recall error frequencies and patterns. Finally, by this stage it should be clear that these insights into the nature of cognitive processes associated with human text comprehension have been significantly facilitated by the distinctive methodology and experimental paradigm developed during the course of the research work described in this thesis.

To begin with we will consider the general conclusions that can be drawn from the combined findings of both studies. The theory that combinations of property attributes presented in novel experiences are represented as belonging to one particular individual by recruiting associations from general knowledge (and more specifically, higher level semantic information) is distinguished from both associationistic and schematic approaches to episodic memory. Associationistic theories assume that associations are formed anew with each experience, and that such a process is theoretically primitive. Our approach does share with associationistic approaches the goal of explaining how elements which could combine to make large numbers of equally plausible experiences are fixed in memory. However, we seek to explain property attribute binding in terms of prior knowledge about the domain. Schematic theories, on the other hand, have ready explanations of how prior knowledge reduces information load by reducing the number of possible combinations of values variables can take, but fail to give an adequate explanation of how orthogonal values of variables (property dimensions) are fixed in memory. Schematic theories assume that subjects mobilise prior knowledge by filling in defaults, but the recruitment theory proposes that subjects may mobilise general knowledge in a much more open ended way, and the results of studies reported here tend to support this more radical view. Detailed analysis of the data and a variety of models of cognitive processes and representation structures reveal that *any* association which serves to pick out one particular combination of elements from other possible combinations is a basis for binding. In the particular case of MIT experimental paradigm together with the results of the second study it has been shown how this strategy is partially facilitated by higher order semantic information such as matching status.

The novel aspect of a recruitment theory can be brought out by comparing these models with semantic network models of memory of both associationistic and schematic kinds. These models (eg, Anderson 1983; Rumelhart Lindsay and Norman 1972) have a level of implementational detail which we have not attempted to provide here. But that does not matter since these theories do not raise the binding problem issue, and this is reflected in the fact that they solve it directly in their implementations by primitive mechanism of these notations, that is, arcs connecting nodes. In our case a more sophisticated and realistic explanation of the binding problem is the single most important motivation for carrying out the present research designed to further our understanding of human text processing and knowledge representation. The data relevant to our current concerns which is brought to support alternative theories is largely reaction times from questions answering tasks and cued recall error rates. The materials used in these tasks, where they have a well defined semantic interpretation, is susceptible to little interference. The binding problem is in fact largely solved in memory before the task begins. This is, of course, true of 'natural' texts: our general knowledge schemata lower the actual memory load enormously. Nevertheless, schemata have many variables whose values are independent of each other, and to study episodic memory we have to focus on how novel combinations of these independent variables are fixed in memory. Thus, we need to answer the question, what is the nature of structures necessary for the representation of a particular set of properties or values? This requires using tasks like MIT in which memory load is much higher than in discursive prose. And it requires theoretical explanation of how general knowledge is recruited to accomplish this task (which is essentially the representation of bindings between a particular combination of properties), Theories which assume a primitive structural solution to the binding problem do not meet this requirement. The alternative mechanism assumed by each approach needs to be explained.

The development of successful direct models of the retrieval errors developed in the first study task demonstrates the *sufficiency* of representations of solutions to the binding problem mediated by the content of associations. However, it was evident that some indirect element in the representations is also necessary. How should we view the choice between completely indirect models which have no referential features derived from the context, and mixed models which contain some referential features along with quantificational features which express binding indirectly? Completely indirect models of solutions to the the binding problem are preferable because they achieve an account entirely in terms of textually explicit properties, without recourse to references to contextual information implicit in the constants. Models with an indirect component are also preferable because their indirectness give an indication of how episodic memory is a knowledge rich process. Do indirect models merely defer the binding problem from being a problem about how features relate to each other, to being about how binding is achieved within features? Not really, since the variables in the propositions that identify the features define the logic of the information features carry, and therefore not of immediate concern for solutions to the binding problem. At a representational level within-feature binding is achieved through the recruitment of existing general knowledge. These knowledge rich processes enable (and support) the representation of novel particulars in episodic memory. For example, how does one represent the fact that there was someone who was both a bishop and Polish, against a background set of possibilities that there might be Polish dentists, Swiss dentists and Swiss bishops? Some linguistically expressible association that fixes the choice to "Polish bishop" and thus excludes the other three possibilities would be sufficient. In our example it could be the term "catholic", which is an adequate association to implement the binding between "Polish" and "bishop". Though, more idiosyncratic or extra-ordinary associations would serve the mnemonic purpose just as well.

Indirect solutions to the binding problem give a degree of representational flexibility at the expense of increasing the inferential complexity of retrieval processes. Considerable inference may be required to synthesize the feature values to provide a faithful description of the state of affairs they represent. How might inferences implicit in indirect models be implemented? These raises questions about the memory representations themselves and the way that the recruitment of associations from general memory is achieved, and, about the inference from representation to response performed during retrieval. While at this stage we can state with some confidence that higher order semantic information has a role to play in the inference making process, a more comprehensive explanation is not possible without a more detailed investigation into the precise relationship between content and representation structure (ie, features and combinations thereof). This would build upon the findings of the second study which indicate that where higher order semantic information is not so readily available the role of content in the representation of associations between variables is more likely to be determined by the lexical items themselves.

So far, Levy (1989) has shown that the inference problem posed by an indirect model of the SSL data can be solved by a connectionist network with hidden units learning by back propagation. The problem requires hidden units because the logical relation between the matching features and the rest are exclusive disjunctive relations, and this is the classic case of a function requiring a hidden layer (Minsky and Papert 1968). The network that has learnt this problem is then shown to generate errors comparable to those observed in humans when the representation is disturbed by random noise. This findings tends to support our notion of features and the nature of their binding but it does not describe or identify the exact nature of the inference process.

Such networks somehow manage to solve the problem of inference from schematic features to response, but they do not solve problem of how the representations of content are encoded. To fully explain the knowledge richness of this sort of memory it is necessary to understand how long term associations are recruited to represent the features that appear in the regression models. This will require modelling of the content of the general knowledge base. Subjects unanimously report that the degree of stereotype of characters is an important determinant of how memorable they are. We are at present engaged in further analysis designed to explore this issue though as yet it remains an open question as to whether such effects can be modelled in this framework. Thus far the present approach has shown how theoretical questions about knowledge representation can be used to design tasks which provide data that bear on representational questions. By interposing a logically explicit analysis of representational features between data and implementation, we gain a clearer definition of what is at stake in choosing between architectures. For instance, a resolution theorem prover would be an adequate inference engine to infer what our indirect data bases represent. But a PDP system promises a less arbitrary account of errors than the account that would result from adding to the theorem prover *ad hoc* mechanisms for generating errors, especially when the present explanation is extended to give an account of the effect of content. In contrast, no matter how natural a computational architecture PDP or connectionist network is for the exploration of interference, as already pointed out in the previous paragraph, it needs to be coupled with techniques which make the logical structure of the transformation from input to output clear.

Studying working memory in a task where semantic structures have to be remembered reveals the very tight way in which processing is oriented toward the structure. On the whole both studies show that what is known about the current individual is what controls the timing of information intake. The strategy of measuring the shape of the functions that relate number of known properties to reading time reveals that these processes are quite modular. Results of both studies show that on the whole they do not change much as new processes come into play in more complicated processing situations. The second study further revealed a possibility of interaction between text format and content. Though given the relatively crude level of analysis we are unable to claim anything more than that the temporal sequence of property attributes or content has a significant effect on the construction processes and the representation of solutions to the binding problem. Our partial account of one reason for this effect appealed to differences in access to higher level semantic information, which of course is dependent on the content itself. Once again, it would seem that a fuller account will have to await further analysis of nature of the processes which consume this time, and more detailed modelling of the effects of lexical content on integration times. For example, does a stereotypical individual such as a "French chef" take less time to integrate than a less typical one, such as a "Welsh dentist"? Results of the second experiment would suggest that this is not the case. But we cannot be certain about this for two reasons. First, because the experiment was not designed to investigate this issue but to see if there was a significant interaction between content and matching status; a question inspired by the results of the first experiment as we pointed out at the end of Chapter 4. The Second reason being that the effect due to difference in access to information about matching status may have overwhelmed the effect due to certain combinations of values (or property attributes).

Investigation of working memory through simultaneous measurements of reading time and errors raises new questions about the relation between working memory and long term memory. In the first study it is the pattern of errors which reveals the difference in status between the primary and secondary individuals, through the confusions of identity when cued by order of introduction. The reading time Model 2 reveals the simultaneous operation of processes that work on the lexical items' semantic properties along with processes of articulatory rehearsal associated with syllabic representations. The balance of these processes is different for the primary and secondary individuals, but for both, there is evidence that the ARL/AAS is used as much for directing semantic processing as for retaining items. In this task, items are actually being retrieved from lexical representations and re-entered into the loop, presumably to expedite their binding to other items in the structure being built; items which are distant in the sequence of presentation. In the second study, reading times and recall error patterns associated with certain matched property dimensions similarly indicated the role of semantic and acoustic similarity on representation and rehearsal processes.

This insight that the representational capacities of even superficial short lived memory systems such as the AAS/ARL may play a role in building durable semantic representations is one of the dividends of organising the scope of memory studies by knowledge representation problems, rather than by the length of time intervening between presentation and test. The ARL/AAS represents sequence information that is one representational format for groupings of individuals and their properties. This information would serve to encode the dimensional information across individuals in this task in working memory. If one can remember that there was no occurrence of "square" in the text, and one knows that the shape of all pairs of individuals are specified, then one can choose "circle" from the menu, for both individuals. This possible implementation of the matchtype features in working memory raises a question about the relation between working memory codes and long term memory codes. We know that the implementation changes: the longevity of acoustic/articulatory information in the AAS is of the order of seconds, and the degree of interference with the representations that underpin lexical occurrence memory in this task must make them quite short lived. Do long term representations consist of implementations of the same features that carry the same semantic information in working memory, or are they also changed features that divide up the information represented in different ways? A partial answer is provided by the results of the second experiment where it is clearly shown that the role of matchtype features in working memory tends to affect the representations of semantic feature of lexical items. The difference in the treatment of matched properties predicted by the reading time model together with their observed difference in error frequencies suggests that working memory implementations of lexical items may vary according to context dependent factors (such as information about matching status). This suggests that the strong hypothesis that long-term and working memory implementations of lexical items have identical semantic features is probably unlikely to be the case. Though, a more reliable answer to this question can be provided by experiments investigating delayed retrieval. If studies of memory for pairs of individuals at longer delays show that these very same features can be found in analysis of memories of longer duration, than it will support the strong hypothesis that these encodings are not so fleeting as their implementations in working memory. Studies of other semantic structures will be necessary to support the belief that such coding devices are widespread.

Contrasting the unpredictable referential switching in the first experimental study with the predictable switching of SSL reveals properties of the central executive mechanism of working memory. What is most surprising is that being able to predict switches enables subjects to so effectively avoid the lengthy processes which unpredictability engenders. Perhaps we can interpret these savings in terms of parallelism: processes of ‘reattending’ to coming items can begin in parallel with processing of the current one when we know where we are going next. An alternative framework is to question whether the same work has to be done in the predictable case. If the temporal organisation of input maps transparently onto the semantics of the structure to be represented, representations of the temporal facts may suffice as working memory representations of the semantic structure. So in SSL’s texts, any first mentioned value on a property dimension is a property of the first individual, and any second mentioned value is a property of the second individual. When unpredictability breaks these mappings down, new representations may have to be constructed, perhaps by creating new temporal facts by rehearsing individuals' properties together.

The second experimental study was partly motivated to enable us to choose between these two frameworks. The results show that temporal information is both available, and plays a significant role, in working memory. However, the notion of notion of temporal information in this experiment is slightly different since reference is no longer unpredictable but dimension order is. This affects the temporal order of higher order semantic information which the representation models show does have an effect on the structure of representations. This we take as evidence reflecting the effect of temporal facts. In particular the results show that texts with the same literal meaning are represented with different structures depending on the temporal order in which this information is presented. This raises an interesting question about whether such differences signify differences in comprehension. A satisfactory answer to this question will require further studies designed to explore the interaction between meaning, representation and the temporal order of discourse text. Any adequate account of the relationship between meaning and representation in memory will need to account for the effect of both, information about higher level semantic structure and the temporal order in which it is presented.

From the above discussion is it abundantly clear that the next stage of research within this paradigm has to address the effect of content. We need to know how individual lexical items affect construction and rehearsal processes and how combinations of *particular* sets of properties are represented as solutions to the binding problem. This approach will reveal a more detailed understanding of not just how general knowledge mediates in the solution to the binding problem, but also what sort of general knowledge is relevant vis-a-vis sets of lexical items that describe an individual. Hence, studies which control the vocabulary set used to describe individuals need to be designed, and the precise effect of different combinations of reading times and recall errors need to be carried out. As already mentioned we have already begun to investigate the effect of certain combinations on rehearsal processes but the prospects look promising.

In contrast to research aimed at increasing our understanding of the role of content, this experimental paradigm is likely to prove useful in investigating the processes and representational structure involved in anaphoric resolution. As pointed out in Chapter 1, in the field of linguistics and knowledge representation work on anaphora far exceeds in sophistication work on attribute binding problem. Various theories of anaphric resolutions, mostly inspired by computer implementations of linguistic theories (see Hirst 1981 for a review), posit elaborate structure to account for anaphoric resolution. A large number of these theories are motivated by syntactic considerations, and assume that there is no systematic interaction with semantics in the resolution process. The current study of the binging problem in human memory would suggest that this might be a bit too simplistic. Our empirical approach is ideal for exploring whether some of the syntactic structure described has any psychological validity. But such research would also increase our overall understanding of human text processing and comprehension as there are a number of similarities between anaphoric resolution and solutions to the the binding problem as both phenomena are subsumed under the general category of reference resolution. Some very simple changes in the MIT text would be enough to allow one to seek out processing and representational similarities between them. It would also provide more psychological account of anaphoric resolution, and one that would benefit from the level of detail afforded by our distinctive methodology and novel perspective on reading time and recall data analysis.

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Appendix A

1. Examples of all texts modes used in experiment 1

The following seven texts are in modes 1 to 7 respectively. All texts are in *forward* format, and, they all have the same matchtype; attributes are mismatched on the first, third and fourth dimension and matched on the second (that is, matchtype -++):

Mode 1 (-++)	Mode 2 (-++)	Mode 3 (-++)
There is a cylinder	There is a cylinder	There is a cylinder
The cylinder is red	The cylinder is red	The cylinder is red
The cylinder is cold	The cylinder is cold	There is a pyramid
The cylinder is thick	There is a pyramid	The pyramid is red
There is a pyramid	The cylinder is thick	The pyramid is hot
The pyramid is red	The pyramid is red	The pyramid is thin
The pyramid is hot	The pyramid is hot	The cylinder is cold
The pyramid is thin	The pyramid is thin	The cylinder is thick

Mode 4 (-++)	Mode 5 (-++)	Mode 6 (-++)
There is a cylinder	There is a cylinder	There is a cylinder
There is a pyramid	There is a pyramid	There is a pyramid
The cylinder is red	The pyramid is red	The pyramid is red
The cylinder is cold	The cylinder is red	The pyramid is hot
The pyramid is red	The cylinder is cold	The cylinder is red
The cylinder is thick	The pyramid is hot	The cylinder is cold
The pyramid is hot	The cylinder is thick	The pyramid is thin
The pyramid is thin	The pyramid is thin	The cylinder is thick

Mode 7 (-++)
There is a cylinder
There is a pyramid
The pyramid is red
The pyramid is hot
The pyramid is thin
The cylinder is red
The cylinder is cold
The cylinder is thick

Appendix B

1. Example texts illustrating matchtype patterns/structures

The following eight texts are in matchtypes, +++, ++-, +-+, +--, -++, -+-, --+, and --- respectively. All texts are in *backward* format, and are in mode 1.

Matchtype 1 (+++)	Matchtype 2 (++-)	Matchtype 3 (+-+)
There is a narrow thing	There is a narrow thing	There is a narrow thing
The narrow thing is soft	The narrow thing is soft	The narrow thing is soft
The narrow thing is white	The narrow thing is white	The narrow thing is white
The narrow thing is a block	The narrow thing is a block	The narrow thing is a block
There is a wide thing	There is a wide thing	There is a wide thing
The wide thing is soft	The wide thing is soft	The wide thing is soft
The wide thing is white	The wide thing is white	The wide thing is black
The wide thing is a block	The wide thing is a beam	The wide thing is a block

Matchtype 4 (+--)	Matchtype 5 (-++)	Matchtype 6 (-+-)
There is a narrow thing	There is a narrow thing	There is a narrow thing
The narrow thing is soft	The narrow thing is soft	The narrow thing is soft
The narrow thing is white	The narrow thing is white	The narrow thing is white
The narrow thing is a block	The narrow thing is a block	The narrow thing is a block
There is a wide thing	There is a wide thing	There is a wide thing
The wide thing is soft	The wide thing is hard	The wide thing is hard
The wide thing is black	The wide thing is white	The wide thing is white
The wide thing is a beam	The wide thing is a block	The wide thing is a beam

Matchtype 7 (-+-)	Matchtype 8 (---)
There is a narrow thing	There is a narrow thing
The narrow thing is soft	The narrow thing is soft
The narrow thing is white	The narrow thing is white
The narrow thing is a block	The narrow thing is a block
There is a wide thing	There is a wide thing
The wide thing is hard	The wide thing is hard
The wide thing is black	The wide thing is black
The wide thing is a block	The wide thing is a beam

Appendix C

1. Instruction given to subjects for the first experiment

Instructions

To begin type in your login name: >*I AM __________

To run the experiment type: >CH."GO"

Your Subject Number is______________

After a few seconds you will be prompted to enter your subject number (see above) and the session (A-H). There will be eight sessions each lasting about 10-15 minutes. Please tick below after completing each session.

Checklist

SESSION	TICK	SESSION	TICK
1	( )	5	( )
2	( )	6	( )
3	( )	7	( )
4	( )	8	( )

The experiment is presented on a BBC computer VDU in 5 stages. Each session will contain 14 texts. Each text will be presented in the following order (after you press the bar to begin the session).

(1) A list of eight words which you can read as long as you like. Some or all of these words are used to describe TWO individuals.

PRESS BAR TO BEGIN TEXT PRESENTATION.

(2) Each text has eight sentences (4 per individual). These are presented one at a time. By pressing the space bar after each sentence you remain in full control of rate of presentation of sentences. Since you will be required to remember the description of

both individuals you should take your time but at the same time please read each text as fast as possible.

(3) At the end of each text you will be asked a question about ONE of the two individuals. Please reply YES or NO, as appropriate, by pressing the "Y" and "N" keys respectively.

(4) Next you will be asked to RECALL either the FIRST or the SECOND individual. It is very important that you are quite clear on this. The FIRST individual is the first presented individual OR the first sentence which describes an individual that is not explicitly introduced till later in the text (ditto for the SECOND individual). To help you to recall the individuals you will be given a list (menu) of 8 words divided into two columns as in this example:

Menu	
TINY	ENORMOUS
SILLY	CLEVER
PINK	ORANGE
TULIP	IRIS

Select the words by moving the "curser" which lights up each word in the menu; use the "X" key to move forward and the "Z" to move back. In order to select a word press the space bar. Once selected the word will appear at the top of the screen. You must select FOUR words to describe each individual - ANY LESS WILL NOT BE ACCEPTED BY THE COMPUTER. If you make an error in your selection then use the DELETE to remove wrong word.

Having selected the four appropriate words (one from each pair) press RETURN. As a check you will be asked whether you are sure of your selection. At this stage you have another opportunity to rectify any errors in your description of the individual. If you think you have made a mistake then press the "N" key and then the DELETE key to remove each word form the right to left. Hence, for example, if you want to change the second word then you will need to wipe out the third and fourth (ie, press the delete key THREE times), and then re-select the second, third and fourth words. Otherwise just press the "Y" key to continue. Please ask me NOW if any of this is still unclear.

MUST ALWAYS CHOOSE ONE WORD FROM EACH PAIR.

DO NOT REPEAT WORDS TO DESCRIBE THE SAME INDIVIDUAL.

---

(5) Finally, the correct description of both individuals, in order of presentation, will be briefly displayed. At this point you are required to do nothing till prompted to press the bar for the next text. At the end of each session you will have to wait a couple of minutes before starting the next one. To begin a session start at the CH.-command (see above) and RE-ENTER your subject number and the session letter. (Note down completed session.)

REMEMBER - YOU SHOULD BE AS FAST AND AS ACCURATE AS POSSIBLE

Once a session has begun it should be completed before you take a break. Breaks between sessions can be as long as required. You should take a break of at least TWO hours after four consecutive sessions.

(1) On completion please remember to logout: >* BYE

Appendix D

1. Values of regression variables in all modes and matchtypes

Definition of variables for the referential discontinuity (first) experiment. (N = NEUTLOAD, + = MATLOAD, - = MISLOAD, F = FOREGROUND, C = CONTOUR).

Sentence	1	2	3	4	5	6	7	8
Mode 1	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC
+++	10000	20000	30000	40000	00101	01100	01200	01300
++-	10000	20000	30000	40000	00101	01100	02100	02100
+-+	10000	20000	30000	40000	00101	01100	01100	02200
+--	10000	20000	30000	40000	00101	01100	01200	01300
-++	10000	20000	30000	40000	00101	00100	01200	02200
-+-	10000	20000	30000	40000	00101	00200	01200	01300
--+	10000	20000	30000	40000	00101	00200	00200	01300
---	10000	20000	30000	40000	00101	00200	00300	00400

Sentence	1	2	3	4	5	6	7	8
Mode 2	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC
+++	10000	20000	30000	00101	30131	01111	02100	03100
++-	10000	20000	30000	00101	30131	01111	02100	02200
+-+	10000	20000	30000	00101	30131	01111	01200	02200
+--	10000	20000	30000	00101	30131	01111	01200	01300
-++	10000	20000	30000	00101	30131	00211	01200	02200
-+-	10000	20000	30000	00101	30131	00211	01200	01300
--+	10000	20000	30000	00101	30131	00211	00300	01300
---	10000	20000	30000	00101	30131	00211	00300	00400

Sentence	1	2	3	4	5	6	7	8
Mode 3	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC
+++	10000	20000	00101	01100	11100	21100	02121	03100
++-	10000	20000	00101	01100	11100	21100	02121	02200
+-+	10000	20000	00101	01100	11100	21100	01221	02200
+--	10000	20000	00101	01100	11100	21100	01221	01300
-++	10000	20000	00101	00100	10100	20200	01221	02200
-+-	10000	20000	00101	00100	10100	20200	01221	01300
--+	10000	20000	00101	00100	10100	20200	00321	01300
---	10000	20000	00101	00100	10100	20200	00321	00400

Sentence	1	2	3	4	5	6	7	8
Mode 4	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC
+++	10000	00101	10111	20100	01111	21131	02121	03100
++-	10000	00101	10111	20100	01111	21131	02121	02200
+-+	10000	00101	10111	20100	01111	21131	01221	02200
+--	10000	00101	10111	20100	01111	21131	01221	01300
-++	10000	00101	10111	20100	00211	20231	01221	02200
-+-	10000	00101	10111	20100	00211	20231	01221	01300
--+	10000	00101	10111	20100	00211	20231	00321	01300
---	10000	00101	10111	20100	00211	20231	00321	00400

Sentence	1	2	3	4	5	6	7	8
Mode 5	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC
+++	10000	00101	10100	21111	01100	22112	02113	03113
++-	10000	00101	10100	21111	01100	22112	02113	02213
+-+	10000	00101	10100	21111	01100	21212	01213	02213
+--	10000	00101	10100	21111	01100	21212	01213	01313
-++	10000	00101	10100	20211	00200	21212	01213	02213
-+-	10000	00101	10100	20211	00200	21212	01213	01313
--+	10000	00101	10100	20211	00200	20312	00313	01313
---	10000	00101	10100	20211	00200	20312	00313	00413

Sentence	1	2	3	4	5	6	7	8
Mode 6	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC
+++	10000	00101	10100	20100	01110	02100	12131	03131
++-	10000	00101	10100	20100	01110	02100	12131	02231
+-+	10000	00101	10100	20100	01110	01200	11231	02231
+--	10000	00101	10100	20100	01110	01200	11231	01331
-++	10000	00101	10100	20100	00210	01200	11231	02231
-+-	10000	00101	10100	20100	00210	01200	11231	01331
--+	10000	00101	10100	20100	00210	00300	10331	01331
---	10000	00101	10100	20100	00210	00300	10331	00431

Sentence	1	2	3	4	5	6	7	8
Mode 7	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC	N+-FC
+++	10000	00101	10100	20100	30100	01111	02100	03100
++-	10000	00101	10100	20100	30100	01111	02100	02200
+-+	10000	00101	10100	20100	30100	01111	01200	02200
+--	10000	00101	10100	20100	30100	01111	01200	01300
-++	10000	00101	10100	20100	30100	00211	01200	02200
-+-	10000	00101	10100	20100	30100	00211	01200	01300
--+	10000	00101	10100	20100	30100	00211	00300	01300
---	10000	00101	10100	20100	30100	00211	00300	00400

Appendix E

1. Examples of all text formats used in experiment 2

The following nine texts are in formats 1 to 9 respectively. All texts are in P x P mode, and they all have the same matchtype; attributes are mismatched on the first, third and fourth dimension and matched on the second (that is, matchtype -++):

Format 1 (-++)	Format 2 (-++)	Format 3 (-++)
There is a chef	There is a chef	There is a chef
There is a vet	There is a vet	There is a vet
The chef is Swiss	The chef is Swiss	The chef is Swiss
The vet is Welsh (-)	The vet is tall	The vet is sane
The chef is tall	The chef is short (-)	The chef is tall
The vet is tall (+)	The vet is sane	The vet is Welsh (-)
The chef is sane	The chef is sane (+)	The chef is sane (+)
The vet is sane (+)	The vet is Swiss (+)	The vet is tall (+)

Format 4 (-++)	Format 5 (-++)	Format 6 (-++)
There is a chef	There is a chef	There is a chef
There is a vet	There is a vet	There is a vet
The chef is tall	The chef is tall	The chef is tall
The vet is Welsh	The vet is short (-)	The vet is sane
he chef is sane	The chef is sane	The chef is mad (-)
The vet is short (-)	The vet is sane (+)	The vet is Welsh
The chef is Welsh (+)	The chef is Swiss	The chef is Welsh (+)
The vet is short (+)	The vet is Swiss (+)	The vet is tall (+)

Format 7 (-++)	Format 8 (-++)	Format 9 (-++)
There is a chef	There is a chef	There is a chef
There is a vet	There is a vet	There is a vet
The chef is sane	The chef is sane	The chef is sane
The vet is Welsh	The vet is tall	The vet is mad (-)
The chef is Swiss (-)	The chef is Swiss	The chef is Welsh
The vet is short	The vet is mad (-)	The vet is Welsh (+)
The chef is short (+)	The chef is tall (+)	The chef is tall
The vet is sane (+)	The vet is Swiss (+)	The vet is tall (+)

Appendix F

1. Instruction given to subjects for the second experiment

Instructions

SUBJECT No.________

To begin type in your login name: >*I AM MUKESH.S____

There will be eight sessions. Each session has 18 paragraphs of equal length. Please tick below after completing each session.

Checklist

SESSION	TICK	SESSION	TICK
1	( )	5	( )
2	( )	6	( )
3	( )	7	( )
4	( )	8	( )

The experiment is presented on the VDU in 3 stages. Each text will be presented in the following order (after you press the bar to begin the session).

(1) Each text has eight sentences (4 per individual). These are presented one at a time. By pressing the SPACE BAR after each sentence you remain in full control of rate of presentation of sentences. Since you will be required to remember the description of both individuals you should take your time but at the same time please read each text as fast as possible.

(2) At the end of each text you will be asked a question about ONE of the two individuals. Please reply by either pressing the "Y" (YES) and "N" (NO) key.

(3) Next you will be asked to RECALL both individuals. You can recall them in whichever order you prefer. To help you to recall the individuals you will be presented with a list (menu) of 8 words divided into two columns as in the following

example:

Menu	
TINY	ENORMOUS
SILLY	CLEVER
PINK	ORANGE
TULIP	IRIS

(4) Select the words by moving the "curser" which lights up each word in the menu; use the "X" key to move forward and the "Z" to move back. In order to select a word press the SPACE BAR. Once selected the word will appear at the top of the screen. You must select *FOUR* words to describe each individual - *ANY LESS WILL NOT DO!* Errors can be removed by using the DELETE key.

(5) Having selected the four appropriate words (one from each pair) press RETURN. As a check you will be asked whether you are sure of your selection. If you are they press the "Y" to continue, otherwise press the "N" key, and then delete and insert in the usual way. DO NOT REPEAT WORDS TO DESCRIBE THE SAME INDIVIDUAL.

(6) Repeat 4 and 5 to recall the second individual.

Please ask me NOW if any of the above is unclear. Remember to note down completed sessions in the table above.

At the end of each session you could either carry on with the next one or take a break. Once a session has begun it should be completed before you take a break. Breaks between sessions can be as long as required. I suggest that you complete at least two sessions per "sitting". You should take a break of at least *TWO* hours after four consecutive sessions.

To continue repeat login procedure outlined at the beginning. The presentation program will automatically present the next uncompleted session.

REMEMBER - YOU SHOULD BE AS FAST AND AS ACCURATE AS POSSIBLE

On completion please remember to logout: >* BYE

Appendix G

1. Values of regression variables in all formats and matchtypes

Definition of variables for the format (second) experiment. (N = NEUTLOAD, + = MATLOAD, - = MISLOAD, * = NON-MATLOAD).

Sentence	1	2	3	4	5	6	7	8
Format Group 1	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*
+++	1000	0010	1010	0110	1110	0210	1210	0310
++-	1000	0010	1010	0110	1110	0210	1210	0220
+-+	1000	0010	1010	0110	1110	0120	1120	0220
+--	1000	0010	1010	0110	1110	0120	1120	0130
-++	1000	0010	1010	0020	1020	0120	1120	0220
-+-	1000	0010	1010	0020	1020	0120	1120	0130
--+	1000	0010	1010	0020	1020	0030	1030	0130
---	1000	0010	1010	0020	1020	0030	1030	0040

Sentence	1	2	3	4	5	6	7	8
Format Group 2	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*
+++	1000	0010	1010	2010	1110	2110	1210	0211
++-	1000	0010	1010	2010	1110	2110	1210	0220
+-+	1000	0010	1010	2010	1110	2110	1120	0121
+--	1000	0010	1010	2010	1110	2110	1120	0130
-++	1000	0010	1010	2010	1020	2020	1120	0121
-+-	1000	0010	1010	2010	1020	2020	1120	0130
--+	1000	0010	1010	2010	1020	2020	1030	0031
---	1000	0010	1010	2010	1020	2020	1030	0040

Sentence	1	2	3	4	5	6	7	8
Format Group 3	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*	N+-*
+++	1000	0010	1010	2010	3010	2011	1111	0211
++-	1000	0010	1010	2010	3010	2011	1111	0121
+-+	1000	0010	1010	2010	3010	2011	1021	0121
+--	1000	0010	1010	2010	3010	2011	1021	0131
-++	1000	0010	1010	2010	3010	2020	1120	0220
-+-	1000	0010	1010	2010	3010	2020	1120	0130
--+	1000	0010	1010	2010	3010	2020	1030	0130
---	1000	0010	1010	2010	3010	2020	1030	0140