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THE REPRESENTATION OF RELATIONAL INFORMATION IN LONG TERM MEMORY

A Dissertation Presented

By

Judy McKinley Brewer

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

February, 1979

Psychology

The Structure of Relational Information

In Long - Term Memory

A Dissertation Presented

By

Judy McKinley Brewer

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ABSTRACT

The Representation of Relational Information
in Long Term Memory
February, 1979

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The memorial information used to judge the relative sizes of two named objects was investigated in a sentence-verification task in which ordinal and semantic distance relationships between the judged items were varied orthogonally. Test sentences were constructed using four seven item subsets of familiar object names drawn from a pre-experimentally ordered twelve item master list. Traditional qualitative analysis mirrored previous findings that reaction time and errors appeared to be affected by ordinal attributes of the items on the judged dimension. Planned contrasts, however, revealed that judgement time and accuracy were predicted only by the semantic (analog) relationships between the judged items. Use of a temporary linear memory array was ruled out and an argument was made that analog relational information was the basis for these memorial comparisons. Both an analog reference-point model and a semantic coding model were found to be adequate to describe the comparative judgement process in this task. However, the data suggested that the descriptions of the memory search and code generation processes proposed by the semantic coding model need refinement. Constraints on the selection of reference-points are also discussed. The findings provide evidence that continuous analog information is available in the long-term memory representation and that analog relationships are utilized in performing memorial comparisons based on real-world knowledge.

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CHAPTER I

INTRODUCTION

How is it that we know the size, shape, color, disease resistance, or keeping quality of an apple? This study concerns the representation of attributes in human memory. In particular, it investigates how information about a certain type of dimension[1] which we shall refer to as "continuous" is coded in memory.

Human memory is not adapted for exact reproduction of previous events, but has the capability of abstracting the general form of events (Bartlett, 1932) and of representing them such that we can use them to act intelligently in the future. In the natural world, no two events or objects are exactly the same. The abstractive nature of memory allows us a flexibility necessary for intelligent operation in this dynamic environment. Of course, the abstraction itself is originally formed of instances, instances chosen from the real world, and we do seem to retain some information relevant to individual instances (Hebb, 1949; Reed, 1972). However, the way in which we choose, and represent, the attributes of the instances will determine what concepts may be formed around them. Thus a complete understanding of the means by which we behave rationally, our cognitive processing, requires that we understand the representation of attribute information in memory (cf. Arbib, 1972; Minsky, 1975).

Most physical attributes are perceptually continuous. For instance, the possible colors of apples range from green through yellow to red. Although we might symbolize the color attribute of a particular apple by calling it "red," we can also say that the "red" of a Russet apple is very different ("more towards the yellow") from the "red" of a Macintosh. Likewise, the possible sizes of apples vary indefinitely between the size of a golfball and the size of a softball. The size dimension is "continuous" because there are an infinite number of possible magnitudes within any particular range. When we consider the abstractive nature of human memory, it is most tempting to assume that these qualities are also coded in memory and processed in a continuous, or $analog_2$ form. There are several reasons to reconsider this assumption, which will be discussed in terms of major classes of models proposed to describe the cognitive processing of continuous dimensional information.

Most of the data relevant to these models comes from studies of comparative judgement. These studies attempt to specify the nature of the cognitive representation and processing of certain ordered (or orderable) relationships. Especially, the focus of much experimental work has been on representation of linear orderings. Related tasks include inference, set inclusion, categorical judgements and others. Although we might think that the real-world applicability of linear ordering studies would be limited, DeSoto (1961, 1965) and others have demonstrated that linear orderings characterize many aspects of human judgement. We often act "as if" we were using universally useful unidimensional lists, even when making multidimensional judgements. In the standard comparative judgement task (cf. Potts, Banks, Kosslyn, Moyer and Smith, 1978), a subject is presented with a pair of items and then is asked to select the one which represents more or less of a particular attribute. For instance, the subject might see words or pictures representing a dog and a horse and be asked to decide quickly which is smaller. Alternatively, the subject may judge the truth of a stated comparative relation (e.g., "The dog is smaller than the horse"). The normal means of measuring this sort of reasoning is through the reaction time (RT or accuracy of the subject. The time required to answer various qestions pertaining to the relations, and the errors in making these decisions, are examined for recurrent patterns.

We are most interested in the competencies humans have for dealing with the _world_, in symbolizing aspects of the world and in representing concepts in memory. Our ultimate goal is development of a generally useful model of these competencies. For this purpose, patterns found across subjects and experimental tasks are most helpful. Knowledge of the way humans deal with linear orderings is, in itself, useful, but we want to avoid results and models that are peculiar to arbitrary and/or artificial settings.

In order to be truly viable, then, any model of comparative judgement, especially one based on linear orderings, must speak to other notions of memory and other tasks. It must deal with robust effects over experiments and be extendable, at least inferentially if not specifically, to areas such as perception and general semantic memory. Secondly, it is preferable that it be intuitively believable.[3] Parsimony is a primary factor in credibility; a model which necessitates numerous _ad hoc_ additions quickly falls from the ranks of serious consideration. With these limits, two classes of models emerge as generally accepted and useful.

Models of Memorial Comparison

The two model classes of interest do not necessarily differ in describing how a perceived event is stored, but rather in the conception of how it is processed. "Perceptual" models assume that the representation used to make a decision is in a continuous form, possibly similar to that of the original percept. "Linguistic" models assume that discrete codes, like those of natural language, are used to make comparative decisions.

Perceptual models. The perceptual models assert that the information used in the decision process is similar to that available in the actual physical object as perceived. Thus information available in a continuous form in the physical world is also available in a continuous form in memory and is used in that form in processing (cf. Potts et al., 1978).

A major impetus in the formation of the models as they now stand was the discovery of an interesting parallel between perceptual and memorial comparison. Things close together on a physical dimension (differing only slightly in magnitude) are harder to "see as different" than things far apart (differing greatly in magnitude). For instance, it is easy to select the dimmer of two lights when one is quite dim and one is very intense. The decision is far more difficult if both of the lights are rather dim, one being only slightly dimmer than the other (Welford, 1960).

Moyer and Landauer (1967) pointed out that this effect can be found for memorial distance as well--the ease with which we can discriminate between stored dimensional values seems to reflect the subjective difference between the magnitudes of such values. Moyer and Bayer (1976) titled this the "symbolic distance effect," to differentiate it from the case in which the referent objects or events are actually present. The effect is quite robust, and has been obtained for several memorial continua (e.g., digits, Buckley and Gilman, 1974; animal size, Moyer, 1973; object size, Paivio, 1975; McKinley, 1975).

Moyer (1973) first made the suggestion that the parallel between the perceptual and memorial conditions was due to an "internal psychophysics" involved in memorial processing. While such a process seems highly plausible, it has proven difficult to define in precise terms. If confusion processes are similar, what sort of internal representation could support a process similar to that of perception?

Perceptual models opt for the most likely candidate and assume that images or analog codes are used and that these are at least second-order isomorphic[4] to continuous representations. If the information is treated directly in its analog form, then processing could 1) be similar to "seeing internally," giving rise to image-processing models,[5] or 2) not rely on imaginal representation, necessarily, but use analog codes in some alternate way to compute a similarity or commonality judgement.

Paivio (1975) and Kosslyn (1975) have most clearly delineated imagery models. Kosslyn (1975) described more clearly what an image might be by describing what it is not: it is not a "picture" in that a picture is concrete, and in that figure-ground perception and contour sharpening are needed for fundamental interpretation. Instead, images are preorganized into objects and their properties, and are meaningful so that we would not forget a random part as would be possible if tearing off the corner of a picture. Although Pylyshyn (1973) has leveled some strong arguments against the use of the image as an explanatory construct, Kosslyn and Pomerantz (1977) have published an eloquent and lengthy reply, arguing that imagery accounts of several experimental findings are at least as adequate as those based on propositional representation. The reader is referred to both papers for a more detailed discussion of the imagery concept. For present purposes it seems sufficient to present a representative set of assumptions used in imagery accounts. The following assumptions were implemented in a computer simulation of imagery by Kosslyn and Schwartz (1978).

1) An image is spatial representation like that underlying the experience of seeing an object during visual perception. These images may be generated from underlying abstract representations, but the contents of these underlying representations are accessible only via the generation of a surface (experienced) image.

2) Only a finite processing capacity is available for constructing and representing images. (Activated detail is limited.)

3) Images, once formed, are wholes that may be compared to percepts in a template-like manner.

4) The same structures that represent spatial in-

formation extracted during vision also support images.

5) Many of the same operators (excluding peripheral functions) that are used in analyzing percepts are also applied to images.

Some subjective support of the image-processing models lies in the almost universal reports by subjects in comparative judgement tasks that they envisioned, imagined, or made a mental picture of the objects to be compared.

Image-processing models do not directly explain comparative judgement by specifying any particular processes, but simply state that the mechanisms used in memorial comparison are directly parallel to those used in perceptual comparison of real objects. These mechanisms, it is assumed, will remain undefined until we understand perception.

The alternatives to the image-processing models, within the class of perceptual models, rely more heavily on the continuous quality of the <u>information</u> utilized than on the representation per se. Banks (1977) has referred to some of these as "analog continuum" models, since they often assume that the mental representation used is a continuum on which items are "placed" for processing. However, models that claim people represent continuous quantities need not claim that they place representations on a continuum before making comparisons. The defining features of such models are: 1) they do not assume image-type representations, but 2) they do assume that the information stored and used for processing is continuous. The term "independent continuous" will be used to denote models of this class. The comparison process such models use is uniform in that "the information retrieved at one point (in time) does not qualitatively differ from information available at a different point" (Holyoak, 1978). Information accumulation proceeds over time, however, allowing increased precision.

Marks' (1972) "discriminal dispersion" model was an early form of such a model, describing the information used as distributions of subjective stimulus magnitudes. More recently, Holyoak (1978) has carefully defined and quantitatively tested a model described earlier by Jamieson and Petrusic (1975). A form of this <u>reference point model</u> seems the most reasonable of the independent continuous class, although a model proposed by Moyer and Bayer (1976) which shares some qualities with the independent continuous will be entertained in the final section of this introduction.

The reference point model assumes that subjects compare two stimuli by computing the ratio of the distance of the first stimulus from a reference point to the distance of the second stimulus from the reference point. This "distance ratio" (or "discrepancy ratio" as Jamieson and Petrusic referred to it) accounts for the symbolic distance effect; the farther apart on the continuum two stimuli are, the larger (smaller) the computed ratio will be and the more quickly the decision may be reached. Reaction time is assumed to decrease monotonically as the ratio moves away from one.[6] The ratio may be computed on an analog scale and thus preserve the analog qualities of the stimuli.

Holyoak (1978) suggests three stages, apart from encoding and response, which are used in the decision process: 1) a gross categorial stimulus-type evaluation (in his particular evaluation, identifying the stimulus as one in which the to-be-compared pair of items lay in one dimensional direction from a reference point, or as one in which the reference point fell between the items on the dimension), 2) assessing the distance from each comparison digit to the reference point, and 3) comparing the two derived distances. The symbolic distance effect could be affected by either stages 2 or 3, but the scale of measurement (e.g., linear or logarithmic) used in stage 2 for computing the distances would determine directly whether subjective magnitude differences would be reflected in the distance function.

Furthermore, if discrete values are retrieved, a direct mental subtraction process could be used in stage 2 to compute specific distances which could be compared in stage 3. But if an analog representation is used, the stage 2 generation and stage 3 comparison processes might be iterative, generating and comparing several sample values.

If the continuous information in the images or analog codes of perceptual models is converted to a discrete form for processing, the line of reasoning implies that actual perceptions are also processed in discrete codes, since these two processes are seen to be analogous. A model making these assumptions is indistinguishable from Banks' linguistic model (1977).

Linguistic models. The semantic coding model proposed by Banks, Clark, and Lucy (1975) and elaborated more fully by Banks (1977) is the single best example of a model which assumes that the representation used in a comparative judgement is discrete. The fact that the model provides an explicit account of memorial comparison makes it especially attractive. Although several propositional models available (Anderson and Bower, 1973; Rumelhart, Lindsay, and Norman, 1972; Pylyshyn, 1973) may well lead to alternate interpretations, no other proposal so far extended has fared well enough to be considered here (cf. Banks, 1977; McKinley, 1975).

The primary assumption of the semantic coding model is that discrete categorical tags are used in the comparison process. The components of the model are the data base, generated codes, and a set of processing mechanisms. The data base may be either temporary data structures or semantic memory; and these data bases may contain continuous information. Banks (1977) prefers to limit analog memory representation to temporary data structures (Banks, Fujii, and Kayra-Stuart, 1976) if admitting it at all, but has not totally ruled out the possibility of analog representation in the long-term data bases. The generated codes, on the other hand, are discrete linguistic codes (i.e., categorical tags) in all cases. The processing mechanisms comprise three serial stages which generate the codes and transform them in order to make a choice. Figure 1 outlines the semantic coding model and will be described in detail in the following discussion. Note that there is a fourth stage "D" which is the response component and has not yet been explicated by Banks and his colleagues.

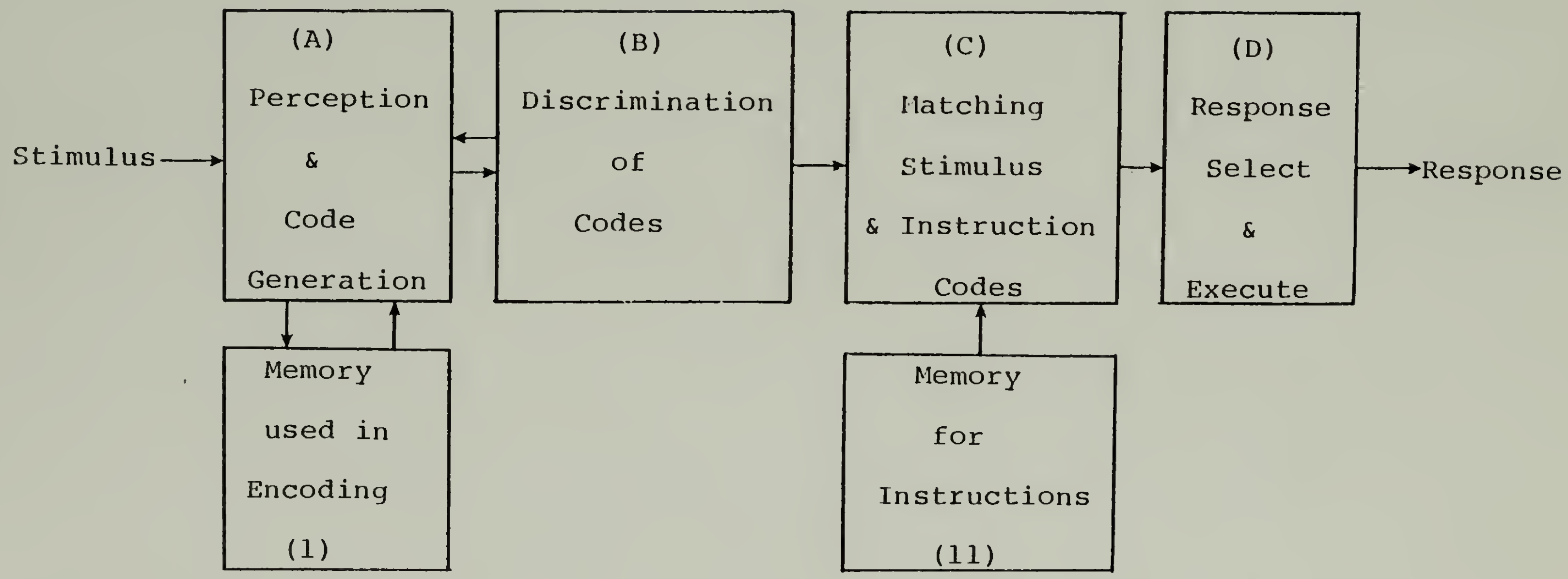

Figure 1: Diagram of Banks' Semantic Coding Model (From Banks, W.P., Encoding and processing of symbolic information in comparative judgements. In G.H. Bower (Ed.) The Psychology of Learning and Motivation: Advances in Research and Theory (Vol. II). New York: Academic Press, 1977.)

The first stage, _A_, is an encoding stage where discrete codes are derived from sensory information by consulting memory. It also generates similar discrete codes directly from the memory representation. These codes are used by all other stages of processing. The second stage, marked _B_ in the diagram, has most of the power in controlling processing. This stage utilizes the pair of codes generated by the first stage; it basically "decides" whether the codes are adequate to distinguish the stimuli. This stage has the power to be an active problem-solver (e.g., to direct the coding stage), but may in simple instances serve more as a passive buffer (perhaps as a "counter" in the manner of accumulating information). It is this stage which is responsible for the semantic distance effect; if items are close together on a dimension, the codes initially generated to define them are more likely to be the same and thus to be rejected by this discrimination stage as insufficient for a choice. Increases in time to make a decision (RT) in a difficult comparison reflect time required to accumulate enough information to generate discriminable codes. Banks describes this relationship as the _availability principle_: the closer together two items are, the less available will be any information which the discrimination process might use to distinguish between them. An example provided by Banks (1977) suggests that items may be easily distinguished if a third item which falls between them on the dimension may be found. Although this particular heuristic is not crucial to the general viability of the coding model, it is a straightforward and testable translation of the logic of the availability principle and will thus be reviewed in detail later in terms of the present experiment.

The third stage (C), and final one of concern here, matches the generated codes to the code for the instructions. The instruction code is assumed to be in the same form as the codes for the poles of the continuum; "pick the largest" is generated as a code of the form "LARGE," or "pick L+."

As previously mentioned, the data base (designated on the diagram in Figure 1 as 1) has not been unequivocally defined by Banks (1977), but he has made some definite suggestions as to the alternatives he would prefer to entertain. Recall that two types of data base are proposed, a temporary one being used for a specific task and a more permanent semantic memory.

Banks' model of the temporary data base assumes a strategy in which subjects "place" items on a special scale useful for a particular task. An analog continuum, such as that described by Shepard, Kilpatric and Cunningham (1975, pp. 130-135) would basically parallel the type of continuum suggested by some of the independent continuous models--with the difference that codes would be generated from the representation rather than processing proceeding directly with the analog information. Alternatively, an ordinal "scaffold" (suggested by Bower, 1971) might be developed by placing items on a scale using their analog attributes, if appropriate, and then discarding or otherwise "forgetting" the analog relationships while retaining the representation of the ordinal relationships. Although either of these temporary data structures could represent interval-scale information (by frequency, DeSoto and Bosley, 1962; by spacing, Moyer and Landauer, 1967; by modifiers, Potts, 1974a, 1975; or by strengths of representation or association on the continuum, Trabasso and Riley, 1975) it is the ordinal qualities which would be the most predominant through effects on coding facility (cf. Minsky, 1975 for his discussion of symbolic descriptions). Ordinal position on the scale would provide the most readily available information for generation of categorical codes which could be compared. It is this quality which makes the temporary structure most useful.

According to the semantic coding model, quantitative attribute information (analog or discrete) is not stored at all in semantic memory, but in most cases is searched for in an inferential fashion when it is needed. Some support for this contention comes from the illustration by Walker (1975) of flexibility and contextual effects in our application of the quantitative attribute knowledge we possess. Banks suggests that the search might include hunting for isolated facts, possibly image construction, or the use of heuristic such as the one previously mentioned in which the search is for a third item which can detail the relation between the two items being judged. We assume that the search process can be more precisely described for any particular task or circumstance.

Applications and Further Qualification of the Models

There appear to be at least three general phenomena found in the majority of comparative judgment and similar tasks. The first of these, the symbolic distance effect, has already been elaborated in the preceding discussion: "The time needed to compare two symbols varies inversely with the distance between their referents on the judged dimension" (Moyer and Bayer, 1976). All of the models considered so far can readily predict this effect.

Perceptual models assume that the representation has the continuous characteristics of the real objects, perhaps in terms of a second-order isomorphism. Within the perceptual class are two subgroups. Image-processing models assume that the representation is a spatial representation like an internalized perception. The symbolic distance effect is the result of the same (unidentified) perceptual mechanisms that produce the parallel effect in judgements of actual objects. Independent continuous models are derived from the assumption that continuous or analog code information is used independent of the reliance on an image-type representation. Reference point models of this independent continuous subgroup describe the comparison process as the computation of a discrepancy ratio of the distance from each of the compared items to a common reference point on the dimension. The farther apart two items fall on the dimension, the more different the ratio is from one and the easier the decision--thus the symbolic distance effect. The semantic coding model assumes that at least the processing representation has the discrete characteristics of natural language. The symbolic distance effect is predicted by the availability principle as it is applied to the search process required to generate discriminable codes of the compared items: the closer the two items are on the dimension, the more difficult it will be to find information which places them in separate categories.

Serial-position effects have frequently been reported for these tasks. The function of interest in this case is the relationship between reaction time and the position of a pair on the scale in question. Two forms of serial position effect have been reported; a symmetrical inverse U-shaped function is usually found in experiments using finite stimulus sets (e.g., Potts, 1972; Banks, 1977), but an asymmetrically bowed increasing (in some cases monotonic) function is often found for pre-experimentally defined orderings (e.g., Moyer and Bayer, 1976; McKinley, 1975).

All models need to rely on a temporary data structure to predict a completely bowed inverse U-shaped function. In experiments which use a relatively arbitrary ordering on which the subjects are trained within the experiment (e.g., Potts, 1974b; Trabasso, Riley and Wilson, 1975; Kosslyn, Murphy, Bemesderfer, and Feinstein, 1977) the bowed serial position function may be a function of differential associations of the placed items with their positions on the scale. Riley (Potts *et al.*, 1978) has suggested such temporary orderings may be constructed in an ends-inward fashion; this would result in "easier" retrieval of items nearer the ends, and accordingly graduated reaction times. For pre-experimental (untrained) finite orderings, the best explanation of a completely bowed function involves differential end-term processing. In the repeated test situations that are almost requisite when using any finite stimulus set, the end-anchors can each become associated with a particular response and present a "quick-exit" processing situation when they appear in the stimulus pair. Several reports have discussed the implications and explanatory limits of the end-term strategies (cf. McKinley, 1975; Riley and Trabasso, 1974; Holyoak and Walker, 1976). For the purpose of the present consideration it is only important to note that data usually show a decreased or absent distance effect for end-term cases. End-term strategies have been blamed, as well, for bowing in what appear to be otherwise monotonic or nearly monotonic functions. The characteristic of immediate interest is that such functions are asymmetric; sometimes they are, in addition, monotonic.

Asymmetric serial functions have been found for the special finite sets of digits, 0-9 (Moyer and Landauer, 1973; Fairbank and Capehart, 1969) and of alphabetic letters (Lovelace and Snodgrass, 1971). In these cases, the asymmetry is assumed to reflect the form of the underlying scale. If the number scale is logarithmic (Banks and Hill, 1974), comparison of small digits will yield faster reaction times than will comparison of large digits when compared. Asymmetric functions have been interpreted by Moyer and Bayer (1976) and McKinley (1975) to reflect scanning processes, and by Woocher, Glass, and Holyoak (1978) as the interactive result of a directionally-biased scan and a symmetrical effect of positional discriminability (i.e., differential discriminability of item positions on an internal array, cf. Crowder, 1976; Trabasso and Riley, 1975).

Serial position effects, then, have primarily been interpreted as evidence of an internalized linear array, perhaps a scaffold as Bower (1971) suggested but not necessarily purely ordinal; and frequently the serial position functions have been interpreted as scan functions as well.

The third effect is actually a special form of the second. The <u>semantic-congruity effect</u> involves an interaction between the form of the question or instruction and the level of the stimuli on the continuum being judged. A comparison can be made more quickly if the items compared are from the end of the scale consistent with the form of the comparative term, i.e., it is easier to decide which of two small items is smaller and which of two large items is larger than, for instance, which of two small items is larger. Sometimes this is a complete "crossover" effect (the ease of the alternate decisions completely reverse at opposite ends of the scale). For other data and continua, one form of the question may always seem to have a certain advantage, but the advantage may not be so pronounced at the opposite end of the scale.

The congruity effect (as it will be referred to in the remainder of this paper, although there are congruity effects other than the semantic--size congruity is one) is very difficult for some models to explain. It was, in fact, the main premise on which Banks and his colleagues developed the semantic coding model. Image-processing models have the greatest problem predicting any change in the pattern of reaction times with the form of the question. For a finite set, it can be assumed that the congruity effect is just another way of presenting either of the serial position effects described above, and that the explanation is essentially the same. If the subject begins scanning at the end of an internalized ordering or scaffold, the items nearest that end will be reached most quickly. If the additional assumption is made that the subject begins at the end designated by the question, the interaction of the congruity effect may be predicted; when asked "Which is larger?," the subject begins at the large end of the scale to look for the items and finds large items most easily. There has been no reason to disbelieve this account for finite sets; however, Banks and Flora (1977) have recently demonstrated the congruity effect for infinite sets as well. In an infinite set design, the effect cannot be the result of processing on a scaffold or other associative structure built up during repeated testing of items. End-item associations are also ruled out.

Kosslyn and his colleagues (1977) have suggested the concept of "recalibration" as an explanation for congruity effects in imaginal comparison. The idea of recalibration is that we set our perceptual mechanisms for a certain range of percepts and that we must readjust this range if it is inappropriate. If we compare the largeness of images in terms of the amount of space filled, we might set a criterion for accumulated "filled space" which is higher for large-range images than for small images. This is easiest to understand in terms of a "frame" in which the image is constructed; we would make a large frame when asked "how large?" and a small one when asked "how small?." If the image turned out to be a small one in a large frame, the sampling process would not be adequately sensitive. We would be required to recalibrate the frame and this process would use time.

This is an expectancy effect in which the instructions define what is to be expected. Banks and Flora (1977) have reported results which question the adequacy of this explanation. They used a task in which instructions were delayed until after the stimuli were presented (in fact they tried several forms of the task) so there could be no expectancy. The data demonstrated convincingly that the semantic congruity effect was unchanged. It is not clear how the "frame" explanation could deal with this data.

The independent continuous models represented by the reference point model fare far better. The expectancy hypothesis would, of course, have applied to this model as well; one simply chooses the reference point designated by the comparative term in the question. Alternatively, however, it is possible to simply select that reference point which is nearest to the items being judged. This alternative readily predicts the congruity effect and it is not dependent upon expectancy (although the point surely might be selected "ahead of time" if the situation made is feasible).

The semantic coding model, of course, has a ready explanation of the congruity effect. The effect is the result of processing in the third stage, where the generated codes are matched with the code for the instructions. If the generated codes are LARGE and LARGE+, which would usually be the case if both items came from the same generally large end of the scale, and the instruction code was LARGE+ (pick the largest), then the match to the instructions would be easy. If, however, the instruction code were SMALL+ (pick the smallest) for the same set of stimulus codes, the matching stage would have to transform the stimulus codes to match the instructions (the transformation is arbitraily assumed always to go in this stimulus-to-instruction direction). Thus LARGE/LARGE+ would be transformed to SMALL+/SMALL before the match could be effected and time would be consumed. The closer the items are to the named end of the scale, the more likely that they will be coded in a "matchable" fashion.

To summarize, all three models can predict the symbolic distance effect, and account for serial position effects as described; however, the image-processing model runs into very serious difficulty with the semantic-congruity effect while the two alternate models predict the effect rather simply.

There are several reasons for rejecting the image-processing subclass besides this one (albeit rather significant) problem. Several recent experiments provide additional negative evidence. First, Holyoak (1977) reported a recent set of experiments attempting to elucidate the function of imagery in mental size comparison. He found that although subjects could utilize images when instructed to do so, there was no evidence that subjects needed to use imagery if not asked to do so, even when comparing very similar items. Secondly, a number of researchers have obtained symbolic distance and congruity effects for "non-perceptual" dimensions. Holyoak and Walker (1976) demonstrated the effects for semantic adjective qualities such as good-fair dimensions, Friedman (in press) reproduced the evaluative dimension effect in both finite and infinite set paradigms (ruling out ordinal temporary data-base explanations which might be used to "back up" the imaginal process), and Kerst and Howard (1977) extended the effect to rankings of animals, countries, and cars on both concrete (perceptual) and abstract (non-perceptual) dimensions. In light of this evidence compounded with the semantic-congruity difficulties, we will discontinue consideration of image-processing models for the time being. It is only fair to add that both Kosslyn, Murphy, Bemesderfer, and Feinstein (1977) and Paivio (1978) have proposed dual-process models (imagery and verbal codes) which answer most of the above concerns. However, in the interest of parsimony, it seems unwise to propose dual processes if a single process model will suffice to explain the data.

It is important to point out that discarding the notion of imagery as necessary for comparative judgement by no means indicates a belief that it does not occur at all. The many phenomena reported by Shepard and his colleagues (e.g., Shepard and Feng, 1972; Shepard and Chipman, 1970) are alone sufficient to defend the concept of the image as a viable construct. A reasonable suggestion has been offered by Holyoak (1977): perhaps in the comparison task the formation of images is a tangential and effortless process which proceeds in parallel with semantic thought, but which is neither used nor needed. Since the image is a "surface" representation and easily described as well, subjects report its presence even when not manipulating it directly. In any case, until there appear to be compelling reasons to reconsider, image-processing models of comparative judgement will not be dealt with further.

The two models holding the most promise are the reference point model (an independent continuous model) and the semantic coding model (a linguistic code model). The data of the experiment to be reported aid in assessing these models for their generality and usefulness.

The factor which most obviously differentiates the models presently considered in this report is the ordinal/interval (discrete/analog) form of information in the representation used for comparative judgements which subsequently produce the symbolic distance effect. The experiment was designed to assess the relative contributions of analog and ordinal information to these decisions. This was and still is an important distinction between the proposed processes.

In order to evaluate the contributions of these variables in a direct way, stimuli were selected in which the ordinal and semantic relationships between items could be manipulated independently. Lists which differed in the ordinal distance or real-world (analog) distance between similar items were constructed. For instance, in the lists dog_1-$bear_1$-$elephant_1$ and dog_2-$elephant_2$-$whale_2$, semantic distance between dog and elephant is equivalent, but the ordinal distance is greater in the first list, as they are separated by another item on the list. Dog_1-$bear_1$ and dog_2-$elephant_2$, on the other hand present equal ordinal distances, but the analog (real-world) difference is greater for dog_2-$elephant_2$. Finally, some pairs had equivalent distance, but different ordinal (serial) position in the list. For example, in

$mouse_3$-dog_3-$bear_3$ and dog_1-$bear_1$-$elephant_1$, dog-bear differs only in serial position--having equivalent ordinal and analog distances. Thus, for any particular pair, judgement times from different lists could be compared to evaluate effects of ordinal and analog distance and ordinal position separately.

Additionally, looking back over the reports produced since the experiment was conducted and with the data to be presented in hand, we could see that there were more specific implications of the presently interesting model classes which could be examined. Some assumptions can be made which, though not yet delineated formally, follow logically from the models as presented. It will be argued that the semantic coding model predicts that strong ordinal effects will appear in comparative judgement mean RT for some tasks even if information is drawn from a long-term data base. To wit: the semantic coding model proposes that a code is generated for each item as it is considered in a comparison. For the sake of clear discussion, we will assume that only a limited number of codes (e.g., large, large+, small, small+) are used for this task. (To assume a greater number of codes would not substantially alter the arguments.) Secondly, we will assume that once a particular code is generated for an item, that same code is more likely to be regenerated than other codes for that item. This may be conceived in terms of attaching a "label" or activating a particular connection or whatever. The point of importance is that the probability of regenerating the code previously selected for an item is increased each time it is selected for that item. Finally, we assume that there is residual activation of information previously accessed. After repeated testing, given these assumptions, the probability with which a particular discrete code is likely to be generated for an item will directly reflect the ordinal relationship of that item to the other items in the list. Items nearer the ends of the lists, for example, will be more likely to "produce" Large+ or Small+ codes. In this way, ordinal information might be the most easily accessible discrete information in long-term memory as well as in a temporary data base scaffold (if one is constructed). This does not imply that a "long-term memory linear array" is constructed, but only that discrete information retrieved from long-term memory will most likely be similar to that derived from a temporary linear memory array.

According to the reference-point model, no particular predictions are made concerning repeated-testing effects. It is possible, of course, that sampled analog information would be "more excited" than other possible samples, but it does not seem that these samples could reflect the ordinal list relationships in any direct way as is the case with discrete codes.

To summarize this argument, the semantic coding model, as interpreted, predicts that in any repeated-test paradigm, ordinal list relationships will be reflected in the symbolic distance effect whenever discrete information is accessed for comparative judgement. This is true even if long-term memory is used for that judgement.

The present experiment was originally designed to assess the relative contribution of semantic and ordinal distance effects. It is now apparent that the semantic coding model predicts that ordinal effects must be present in a repeated-set paradigm. An absence of semantic distance effects creates difficulties for both models.

Present Experiment

The experiment used four seven-term size-orderings chosen from a single list of twelve names of familiar objects. Thus no experimental training was required in using the orderings in a sentence-verification paradigm, parallel to that of McKinley (1975), in which reaction times and errors were recorded. The four lists were constructed such that ordinal separation and semantic distance could be examined orthogonally. A means of evaluating the serial position effect was also included. Each of the items was tested repeatedly over a two-day period.

CHAPTER II

METHOD

Subjects

A total of thirty-two subjects served in the experiment. They were undergraduates who participated for experimental credit toward course grades or to complete a course requirement. Each subject participated in one fifty-minute session on each of three consecutive days. Only the first two days' data are of immediate interest, since the third day constituted a separate experiment.

Apparatus

Stimuli were presented on a video monitor controlled by a PDP-8E computer. Reaction times were obtained and recorded under program control using a response console with two trigger-switches and a central button which could be illuminated. The trigger-switches were labelled "True" and "False" appropriately.

Materials

A twelve-item list, the ten-item "objects" list used in McKinley's (1975) previous study with two new items added, was used to construct four separate seven-item lists with common elements. The two additional items were chosen from a list generated by six subjects who were asked to name all the items they could think of which were household objects larger than a briefcase and smaller than a bicycle. The names of all the items were printed on cards, one to a card, including McKinley's original ten items. The same subjects were then asked to order all the cards according to the size[7] of the items named and the two most consistently placed new items were selected and added to the list. The twelve-item list is indicated in Table 1, along with the four seven-item lists constructed from it.

Four seven-item test lists were chosen such that two distance measures, semantic distance and ordinal separation, could be examined independently. In general, single ordinal steps in List A represented smaller semantic distances than did ordinal steps in Lists B, C, or D. Since the items were the same for all lists, semantic distance was equated while ordinal separation and serial position were varied. In addition, checks for the confounding effect of overall serial position of a pair were included.

The major critical items for the analysis were those from positions 4, 6, and 8 in the original twelve-item base list. Note that List A constituted a complete series

1. Pin
2. Toothpick
3. Razorblade
4. Matchbook
5. Teaspoon
6. Lightbulb
7. Brick
8. Telephone
9. Briefcase
10. Typewriter (new item)
11. Television (new item)
12. Bicycle

Test Position		1	2	3	4	5	6	7
List	A	3	4	5	6	7	8	9
	B	1	2	4	6*	8	10	11
	C	2	4#	6	8	10	11	12
	D	1	3	5	7	9	11	12

* Insert item 7 on Day 3

\# Insert item 5 on Day 3

Numbers refer to position of items in the original twelve-item list.

Table 1: Structure of the twelve-item list and the four test lists constructed from it. (McKinley's, 1975, Objects list plus two new items.)

of items 3 through 9 of the base list. Thus items 4 and 6 were two ordinal steps apart, as were 6 and 8. In List B, these items were adjacent. In List C, these items were again adjacent, but the serial position of the items was altered such that pairs including items 4, 6, 8, and 10 appeared at earlier positions in the serial order. Furthermore, pairs in List C which included item 4 had the same initial serial position as corresponding pairs in List A. List D was a control list, providing adjacent-pair (single-step) situations for pairs 3-5, 5-7, and 7-9. Note that this was a second situation (comparable to List B, but with different semantic items) in which a single ordinal step in List A represented less semantic distance than the equivalent step in the alternate list.

The seven-term orderings allowed 21 unique pairings of items for each list. The test statements were constructed from these in the form "A is smaller than B". The comparative "smaller" was always used. There was no interest in checking for a congruency effect as it had already been demonstrated for the objects list in the similar task used by McKinley (1975). The term "smaller" was selected for use because it produced more stable data in that study than the question using "larger."

The pre-test materials were four sets of seven cards each, one set for each list, with the name of a different item from the list printed on each card next to a line drawing of the object. Each subject saw only one of the sets (lists).

Procedure

The subjects were run individually in three sessions, each consisting of a practice block of trials and eight data-collection blocks.

For the pre-test, each subject was given a set of cards and asked to put them in order according to size of the items indicated. S/he was allowed to do this in any manner (laying them out, putting them in a stack, etc.) or direction (largest to smallest or vice versa). The order and manner were recorded. If more than three items of the subject's ordering conflicted with the chosen ordering, the subject was dismissed from the experiment with appropriate credit. If three or fewer items conflicted, the experimenter pointed out the disagreement(s) and asked the subject if s/he agreed that the ordering being used for the experiment was a reasonable one. If the subject agreed, the cards were randomized and the subject was asked to order them again. If agreement was not reached on this trial, the subject was dismissed with appropriate credit. If agreement was reached, the cards were reshuffled and the subject was asked to reproduce the order to a criterion of two consecutive correct orderings. No subject was run more than three pre-test trials, and no subject was used who did not agree that the ordering was a rational or natural one for him or her. In addition, any subject whose error rate rose above 5% (17 errors on either Day 1 or Day 2) on the data-collection trials was dismissed from the experiment and given appropriate credit. Only two subjects exceeded the error limit and had to be dismissed. The subjects dismissed were from the C and D list groups and each made 18 total errors.

There was a practice block of 10 statements randomly selected from the possible set at the beginning of each day's testing. In addition, data from the first two trials of each data-block were discarded and the test statements replaced in the pool.

Each block of trials included one presentation of each of the twenty-one pairs at each truth value. The forty-two resulting test sentences were randomized within a trial block. For each trial, a statement appeared on the screen and remained there until the subject responded "true" or "false" by pulling the corresponding trigger. Subjects were instructed to respond as quickly as possible without making errors. At the end of each block, a central button lit up and the subject's mean RT and error rate appeared on the screen to assist him/her in monitoring his/her performance. The subject pressed the lighted central button to continue to the next block.

Eight subjects were tested with each list; half used their dominant hand for the "True" response and half used their non-dominant hand. List (A-D), and Hand (Dominant or Non-dominant for True), formed eight independent groups for between-subject analysis. Day (1 or 2), Truth Value (True or False) and Pair (1-21) were within-subject factors.

CHAPTER III

RESULTS

Mean correct reaction times were calculated over the eight data collection blocks for each of the forty-two pairs for each subject for each of the first two days. The number of correct responses was calculated similarly. A five-factor analysis of variance was performed on each of these measures with List, Hand, Subject within List-Hand, Day, Truth Value and Pair as factors. As was expected, given previous data, there was no effect of the dominant or non-dominant hand being used for the "True" response, so it was possible to collapse the analysis across the Hand factor to gain power. Anova results reported will be from the collapsed analysis. The average error rate was very low, 3.25%. All error analyses and results paralleled those for reaction time, and the conditions that were slower also had more errors, thus belying a speed/accuracy trade-off. The specific error analyses will not be reported, but error data noted when it does not parallel RT.

Analysis of Variance Results

Main interest was in the List and Day main effects and in the List by Pair interaction. Appendix A summarizes the results of the full analysis. The analysis of variance provided a general look at overall list, response bias, and practice effects. Since the ordering of the individual pairs for such an analysis was logical but necessarily arbitrary, the expected main effect of pair was examined more closely by inspecting qualitative patterns in the data and through specific planned contrasts of particular pairs.

Table 2 shows the average reaction times and percentage errors for each list. The main effect of List was significant ($F\ (3,28) = 3.92,\ p < .05$). Since the lists were the same length, list differences should be attributable to item differences and differences in semantic distance between items. Of course, when the average semantic distance between items in a list increases, its range increases. Range differences were very slight in this experiment; List A's range was the only one noticeably smaller. Previous studies (McKinley, 1975) have indicated that range was probably a weak factor at best.

List	A	B	C	D
Mean RT	1558.00	1126.78	1533.73	1255.65
Percent Errors	2.73	2.93	3.08	2.88

Table 2: Average reaction times and percentage errors by list.

Lists B and C varied in only one item, so that the apparent difference between them is difficult to assign. Since the main effect of List, even with items of totally different classes (animals, balls, fruits, and objects) was not very strong in McKinley's (1975) study, item differences would not be expected to account for much variance. Moreover, List D, with an almost entirely different set of items, had an average reaction time very close to that for List B. It seems reasonable to suppose, then, that the List C average RT reflects a maverick variable to be explicated through qualitative analysis.

The difference between the List A reaction time and those for Lists B and D may have been produced by a general slowing of the RT's for List A. This would be expected if the Symbolic Distance Effect was largely controlled by semantic distance. Overall semantic distance (range) could have been a factor, but more compelling is the fact that the average semantic distance between pairs was less for List A than for any of the other three lists, though ordinal distances were obviously the same. The general slowing of reaction times for List A would support the hypothesis of strong semantic components in the Symbolic Distance Effect. Note that increasing the absolute size differences (semantic differences) decreases RT but does not significantly change errors; this has been demonstrated by Potts (1974a) and by Moyer and Bayer (1976). It is as if subjects were changing criterion to keep error rate constant and thereby lowering RT. This is a <u>between</u> list speed-accuracy tradeoff.

Similarly, the significant List by Pair Interaction ($F\ (60,560) = 2.47$, $p < .05$) indicated a strong semantic component, since pairs in the analysis were defined by ordinal locations. If pairs varied across lists, it had to be due to the different semantic components of the pairs.

The significant Day main effect ($F\ (1,28) = 121.3$, $p < .05$) evidenced the fact that subjects were much faster (approximately 500 msec.) on the second day. Day did not interact in an important way with anything except

Truth Value. This was due to people learning about the large end-anchor as discussed below.

Qualitative Patterns

Qualitative analyses generally showed that the patterns of data normally referred to in discussions of the Symbolic Distance Effect, serial position effects, and end-anchor effects were replicated for this study.

Figure 2 illustrates the distance effect in the data averaged over days. Mean reaction time was inversely related to the distance (number of ordinal steps) between terms in a pair, decreasing as the number of ordinal steps between terms increased. The slopes for all lists are similar, with the intercepts for Lists A and C reflecting the aforementioned overall increases in RT.

Figures 3, 4, and 5 illustrate serial position curves very similar to the asymmetrically bowed curves frequently found in comparative judgement tasks. The figures demonstrate the effects for pairs of stepsize 1 (adjacent pairs), 2, and 3 respectively within each of the lists. Even with end-anchor pairs eliminated, 10 out of the 12 best-fitting lines had slopes greater than zero. This proportion of positive slopes was significant by a simple sign test ($\underline{Z} = 2.07$, $p < .02$).

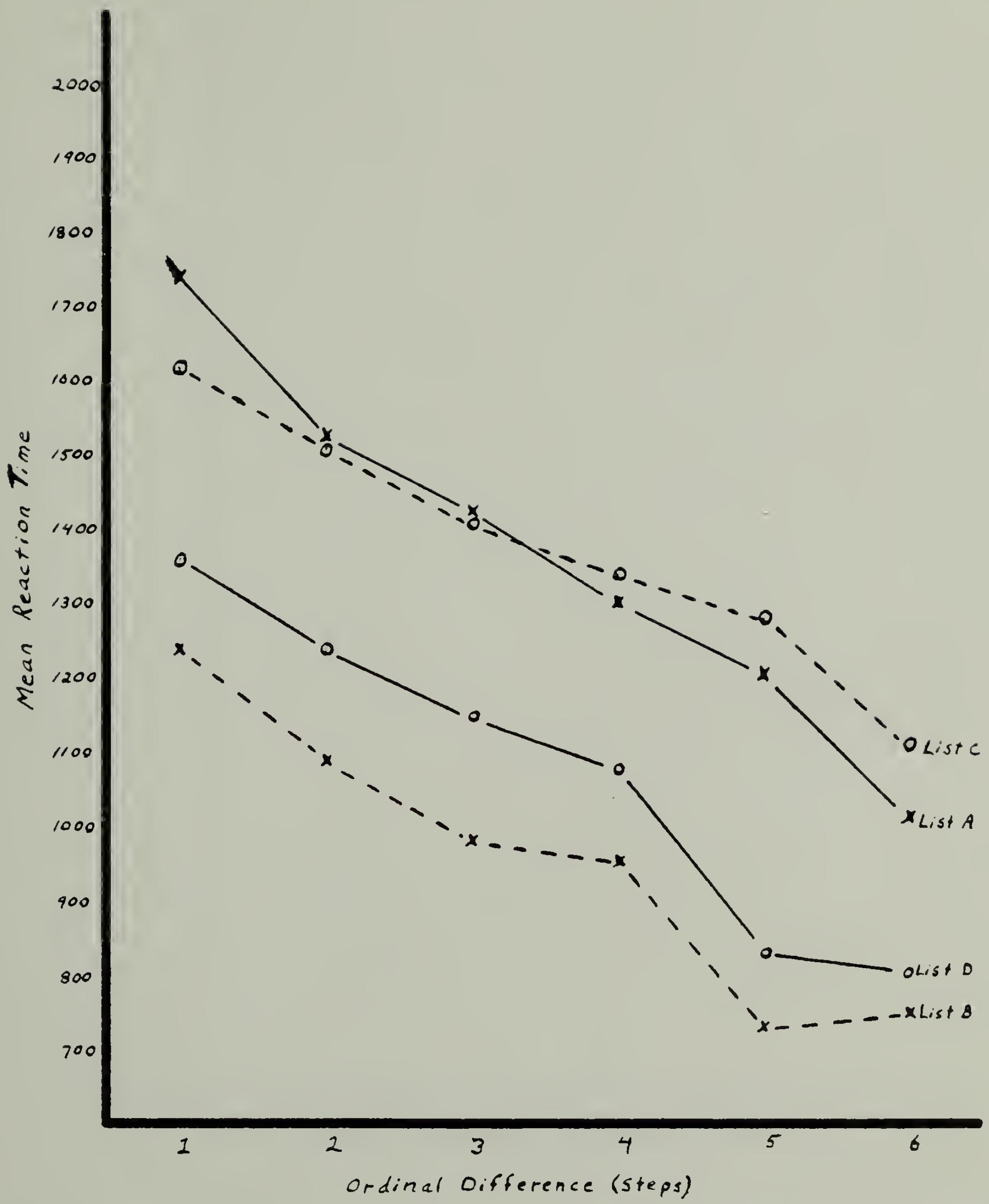

Figure 2. Mean reaction times summed over steps of equal distance and averaged over days. Ordinal difference. 1 = adjacent pairs.

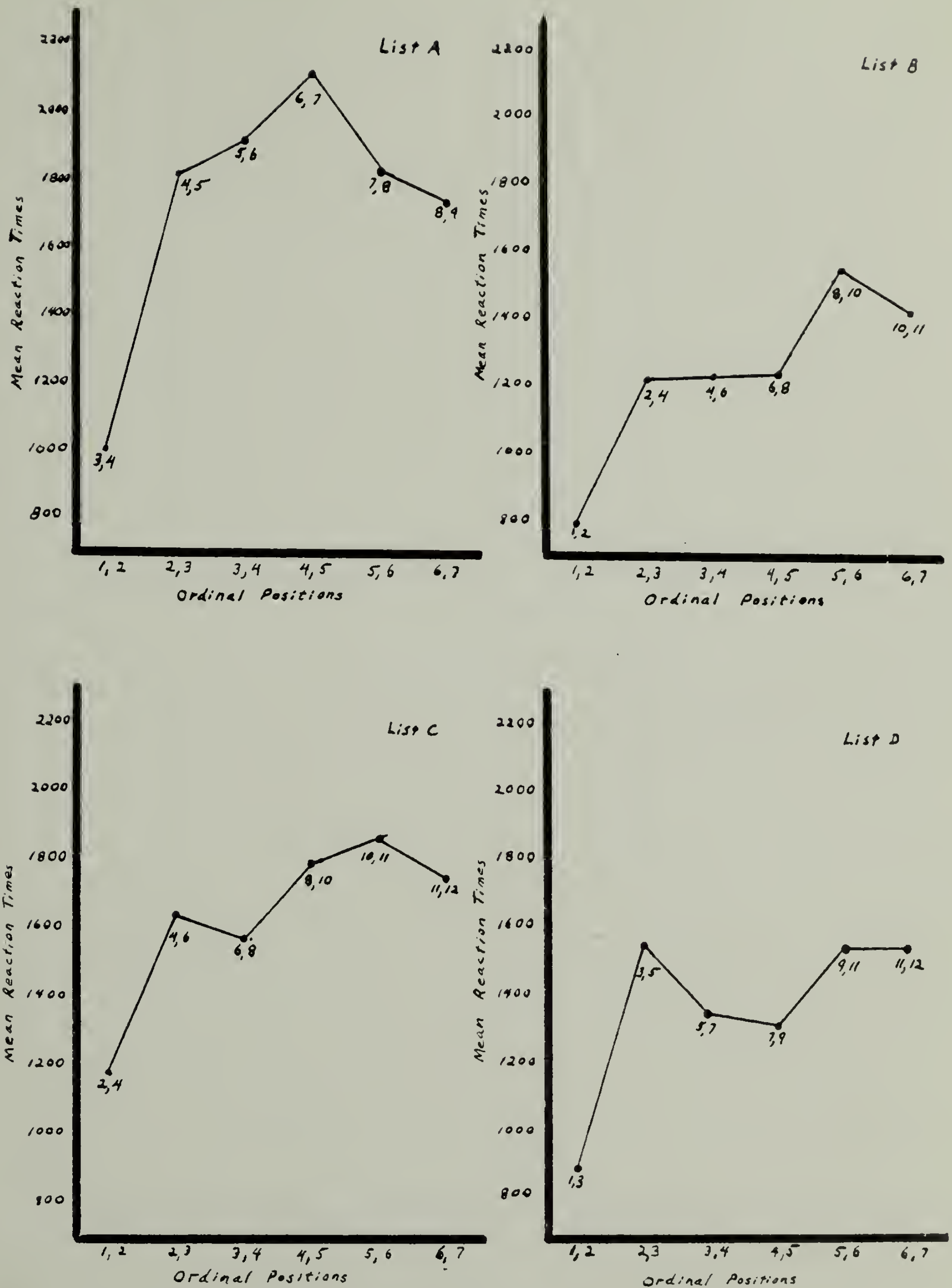

Figure 3. Mean reaction time as a function of serial position for pairs of ordinal difference 1. Numbers near the points correspond to position of the items on the master list.

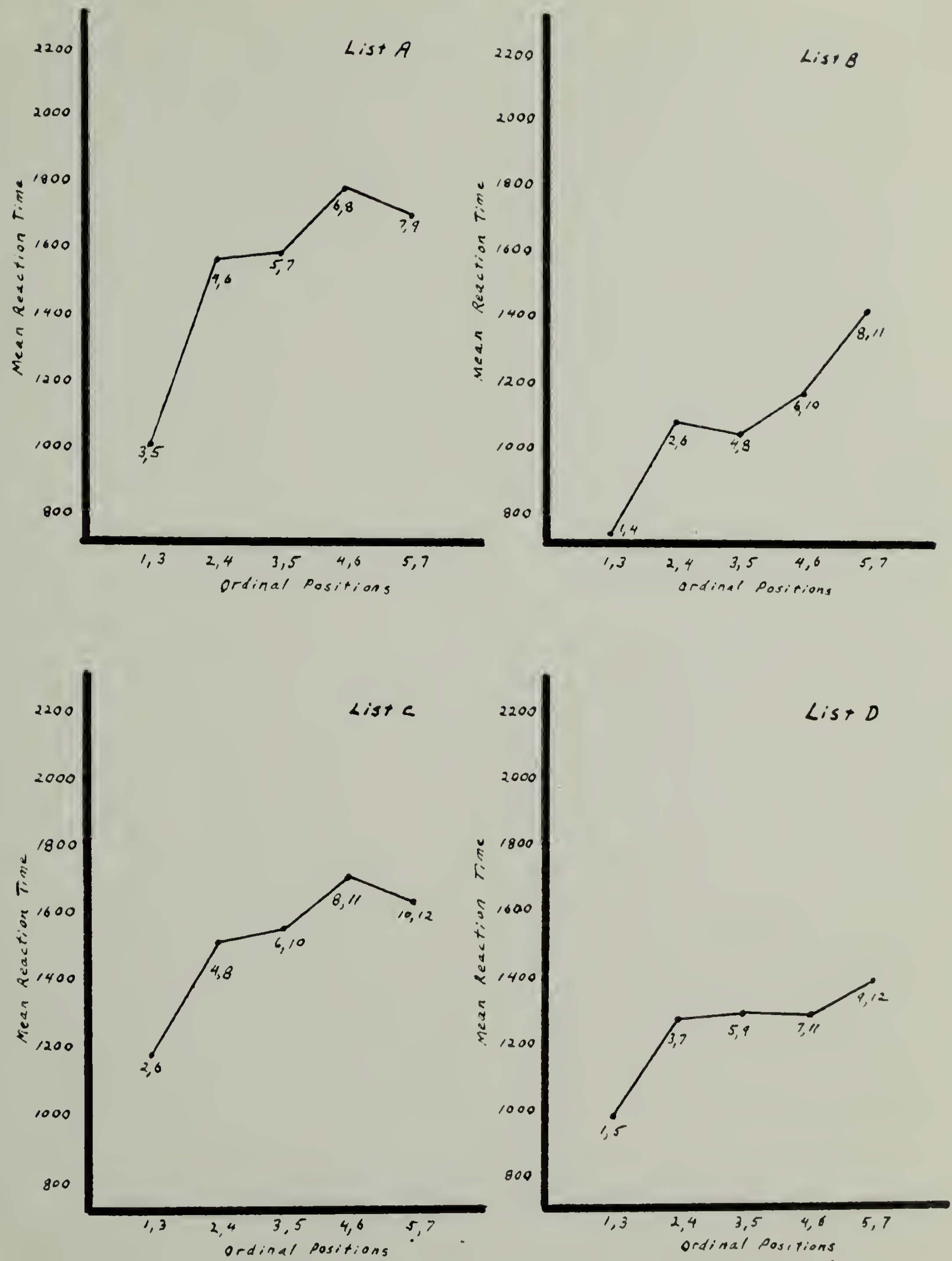

Figure 4. Mean reaction time as a function of serial position for pairs of ordinal difference 2. Numbers near the points correspond to position of the items on the master list.

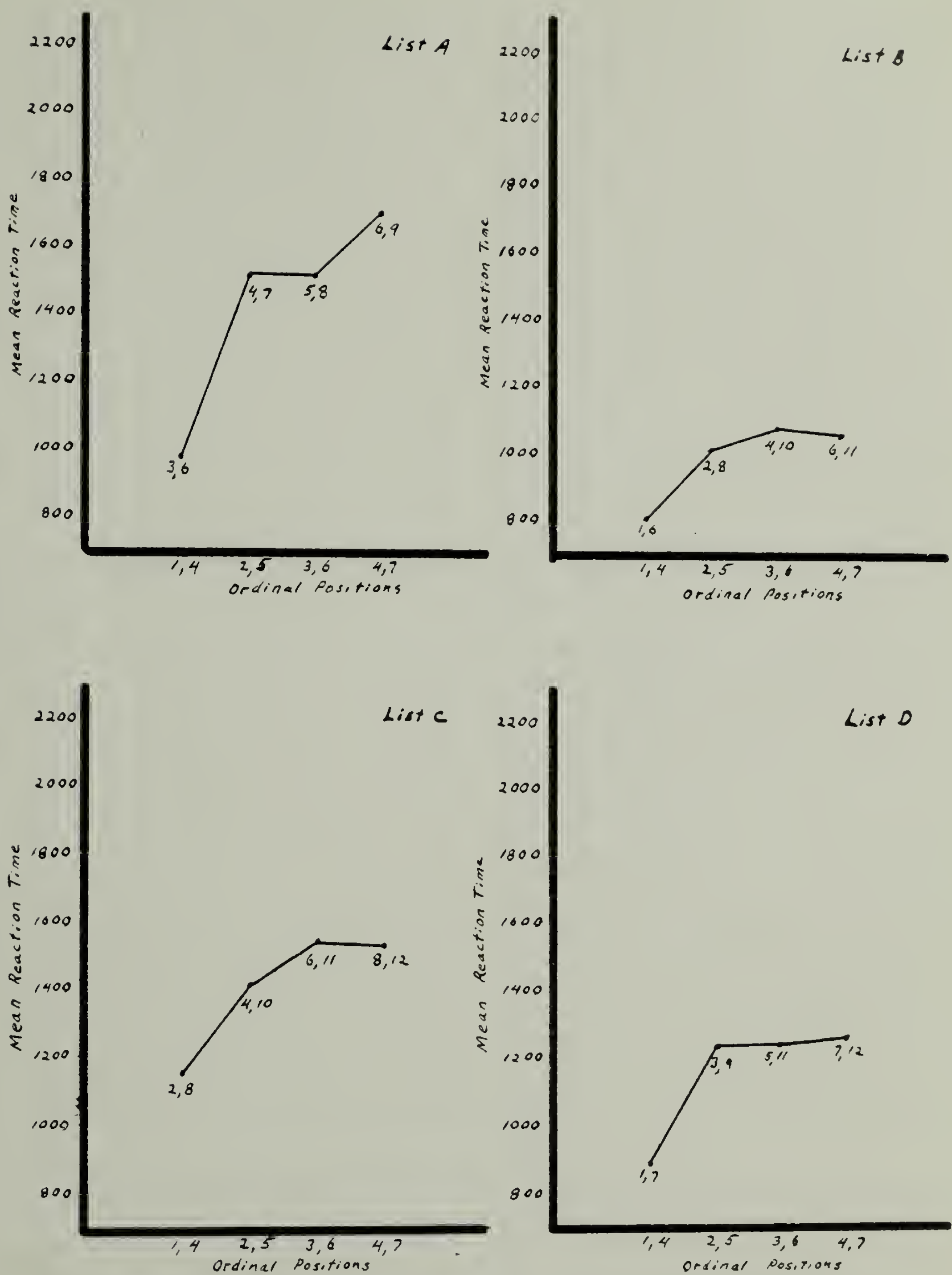

Figure 5. Mean reaction time as a function of serial position for pairs of ordinal difference 3. Numbers near the points correspond to position of the items on the master list.

Figures 6 and 7 graphically demonstrate end-anchor effects. Note that these curves are plotted in the same manner as the distance effect curves of Figure 2 except that only anchor pairs are included. Distance between the anchor item and the other member of the pair increases along the abscissa. Most of these end-term functions show a decreased or absent effect of distance, being more flattened than the comparable curves of Figure 2 and indicating differential processing of pairs containing end terms. The effect of an end-anchor strategy was most evident in both the "true" and "false" curves of Figure 6 for the small anchor. This might be expected, since the comparative was always "smaller" (vide Woocher, Glass and Holyoak, 1978). For "true" pairs, those in which the small anchor occurred on the left (i.e., "A (anchor) is smaller than X"), the curves are especially flattened, indicating a universally quick acceptance. Moving to Figure 7, we see that for "false" pairs, in which the large anchor appeared on the left and presented a quick-reject opportunity, the curves are again nearly flat. List D presents the most ambiguous support for a large-anchor effect.

The end-anchor plots also revealed the source of the problematic difference in the average reaction time

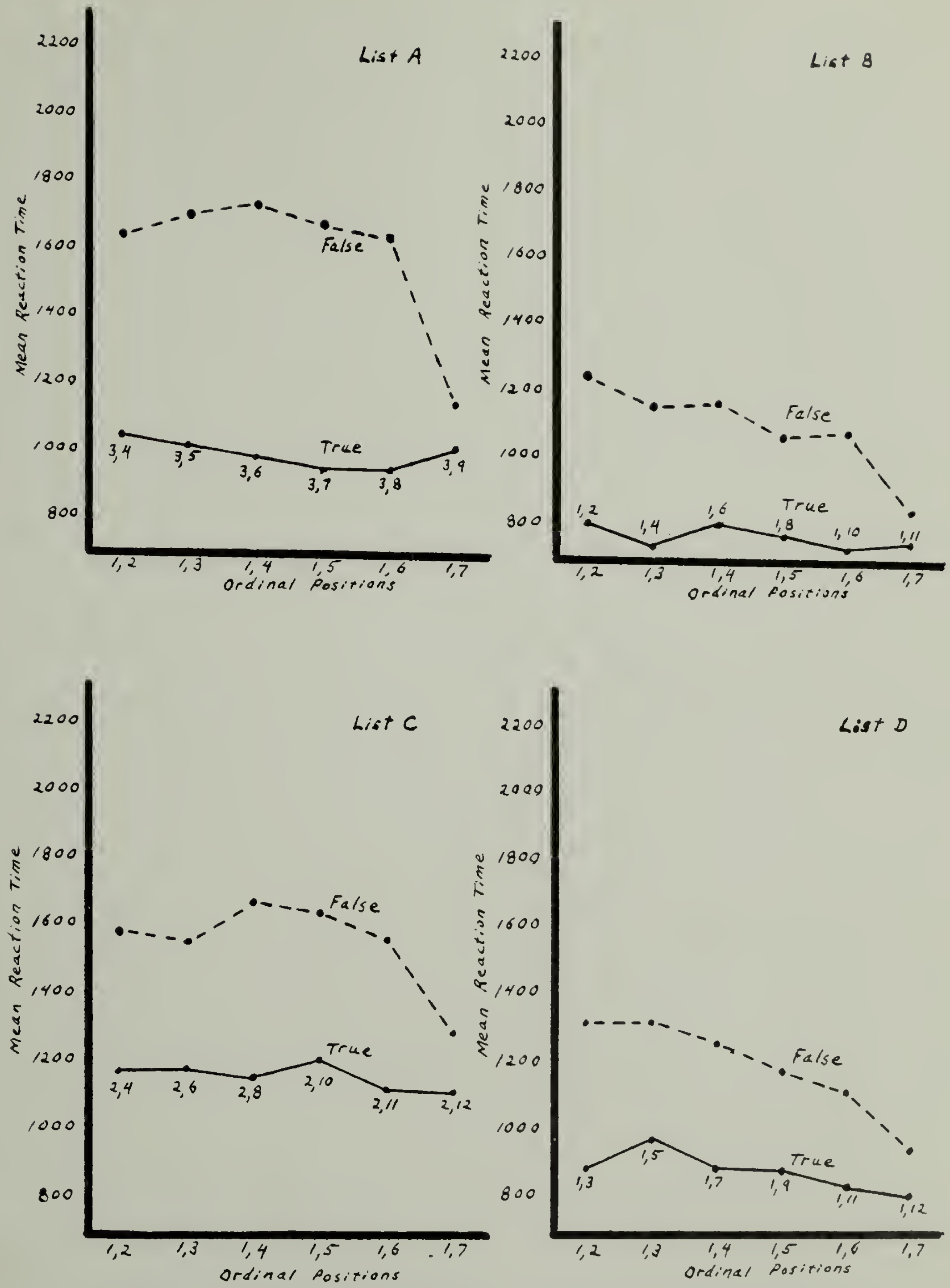

Figure 6. Mean reaction times for anchor pairs in which the small (position 1) anchor occurred.

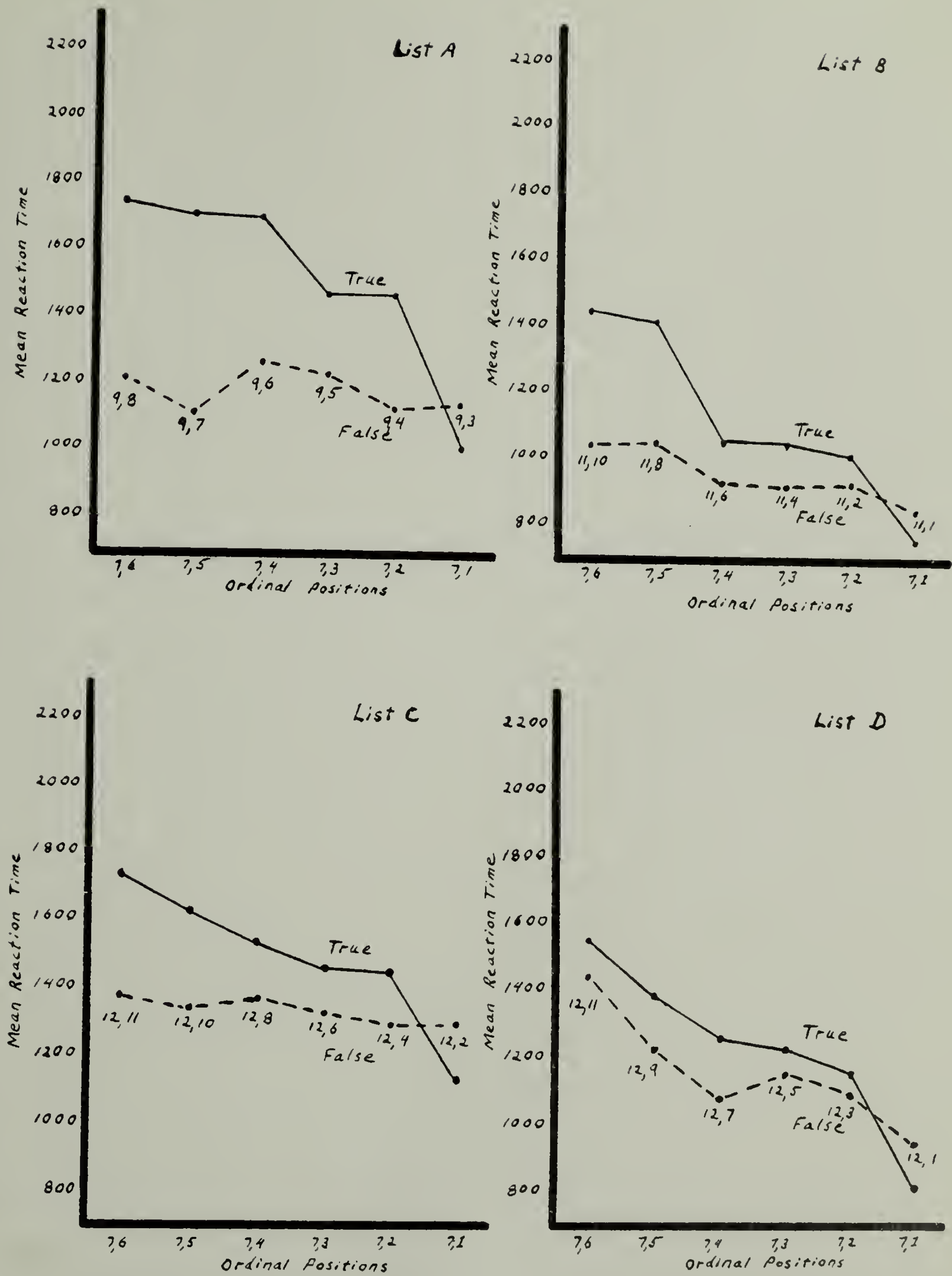

Figure 7. Mean reaction time for anchor pairs on which the large (position 7) anchor occurred.

for List C, compared to the other lists. Referring again to Figure 6, note that the response time for small-anchor true sentences is not the same across lists. This is remarkable, since it supposedly reflects a standard quick-exit response (cf. Potts, 1972, 1973; Trabasso and Riley, 1975; McKinley, 1975; Moyer and Bayer, 1976). It is logical to assume that the differences between these flat-response times reflect overall response-time imbalances between the subject groups used for each list. The slowing of List C is attributable to uninteresting subject differences.

Table 3 presents the average reaction times for the four lists and the differences between those RTs. The second row of figures indicates the average small anchor response times and the differences between those response times. The third row shows the average list RT differences which remain unaccounted for by the differences in quick-response anchor times. This last row indicates that approximately 150 to 200 msec. of the List A RT difference remains unaccounted for by the above analysis, adding credence to the interpretation of that difference as attributable to the closer semantic spacing of that list. Finally, as expected, all subjects in this task reported, as in previous tasks, that they believed they had used imagery. Some

List	A	B	C	D	|A-B|	|B-C|	|C-D|	|A-C|	|B-D|	|A-D|
Average Reaction Time	1158	1126	1533	1255	432	407	322	25	129	308
Average Small Anchor Response Times	996	766	1160	880	230	394	280	164	114	116
RT Differences Unaccounted for by Anchor Adj.	*	*	*	*	202	6	42	139	15	192

* These quantities are omitted, as they have no clear referent within the present discussion.

Table 3. Comparison of average reaction time and small-anchor response time relationships between lists.

subjects reported "overlaying" the images and some reported creating adjacent images. One subject reported not requiring imagery on the second day, but could not describe how he did perform the task.

Contrasts

The cardinal concern of this study was the relative impact of semantic versus ordinal attributes on judgement time. To examine these influences of semantic distance, ordinal position, and step size (ordinal distance) more systematically, three major contrasts were performed using only those pairs in which these factors varied orthogonally. Two forms of score standardization were employed in order to confirm the accuracy of the results. The contrasts were performed separately for true and false sentences, making a total of six contrasts for each type of standardization; accordingly, the rejection level was set at E_c = .01 for each contrast, thus holding the E_w below .10 as suggested by Scheffe (cit. Myers, 1972, pp. 360-364). Table 4 lists the pairs and scores used in the contrasts.

First all scores were adjusted individually for each subject by his or her estimated quick-response time. Each subject's average small-anchor true response

	Pair	List		Original Score	Appropriate Test Adj for Subj Mean	Conservative Test Adj for Anchor Est
			Steps			
Stepsize	4-6	C	1	1631.11	97.37	471.40
	4-6	A	2	1570.95	12.94	574.70
	4-6	B	1	1213.36	87.07	446.89
	4-6	A	2	1570.95	12.94	574.70
	6-8	B	1	1224.47	98.18	458.00
	6-8	A	2	1781.29	223.38	785.03
	5-7	D	1	1338.05	82.39	457.71
	5-7	A	2	1589.48	31.47	593.22
			Positions			
Ordinal Position	4-6	B	3,4	1213.36	87.07	446.89
	4-6	C	2,3	1631.11	79.93	471.40
	6-8	B	4,5	1224.47	98.18	458.00
	6-8	C	3,4	1557.21	23.47	397.50
	8-10	B	5,6	1558.47	432.18	792.00
	8-10	C	4,5	1771.88	238.14	612.18
	4-10	B	3,6	1071.64	-54.64	305.17
	4-10	C	2,5	1408.51	-118.18	248.81
	10-11	B	6,7	1442.96	316.66	676.48
	10-11	C	5,6	1851.18	317.44	691.47

Table 4: Pairs and Standardized scores used in planned comparisons.

("True" RTs only)

	Pair	List	Positions	Original Score	Conservative Test Adj for Subj Mean	Appropriate Test Adj for Anchor Est
Semantic Distance	4-5	A	2,3	1809.33	251.32	813.08
	4-6	C	2,3	1631.11	97.37	471.40
	5-6	A	3,4	1913.12	355.11	916.87
	5-7	D	3,4	1338.05	82.39	457.71
	6-7	A	4,5	2113.01	555.01	1116.76
	6-8	B	4,5	1224.47	98.18	458.00
	4-5	A	2.3	1809.33	251.32	813.08
	3-5	D	2,3	1545.79	290.13	665.44
	10-11	C	5,6	1851.18	317.44	691.47
	9-11	D	5,6	1538.89	288.23	658.55
	4-6	A	2,4	1570.95	12.94	574.70
	4-8	C	2,4	1509.36	-24.37	349.66
	5-7	A	3,5	1589.48	31.47	593.22
	5-9	D	3,5	1291.36	35.70	411.02
	6-8	A	4,6	1781.29	223.28	785.03
	6-10	B	4,6	1176.04	49.75	409.57
	8-11	C	4,6	1706.84	173.10	547.13
	7-11	D	4,6	1281.66	26.00	401.32

Table 4 continued. ("True" RTs only)

time (the average of the six pairings (1,2 through 1,7) in which the small anchor appeared on the left) was subtracted from each of his or her reaction time scores for "True" sentences. The average large-anchor false reaction time (the average of the six pairings (7,6 through 7,1) in which the large anchor appeared on the left) was likewise subtracted from the reaction times for "False" sentences. This was done separately for each day's scores, and the results combined.

Semantic distance demonstrated a reliable effect with the predicted difference tested against zero for both true and false response times ($\underline{t}$ (1,28) = 2.95, true pairs; $\underline{t}$ (1,28) = 3.12, false pairs). This means that with ordinal position and stepsize held constant, the semantic distance represented within a pair significantly affected reaction time. This is evident in the individual pairs of "anchor adjusted" scores listed in Table 4 for the semantic distance contrast. (Only "True" scores are indicated in the table, false scores were essentially similar.) For instance, list positions 2 and 3 are matchbook-teaspoon and matchbook-lightbulb in Lists A and C respectively. The adjusted scores are 813 and 471 msec.: with all ordinal variables held constant the analog differences in size were reflected in the reaction times. This relationship holds for each of the nine simple comparisons used; the pair with greater semantic distance invariably has a shorter RT and the magnitude differences are relatively consistent.

The ordinal position evaluation showed no significant effects. With semantic distance and stepsize held constant, serial position in the list had no effect. Again, examining individual paired sets supports the overall contrasts: only three of five differences are in the predicted direction and these are small.

Finally, the stepsize contrasts showed an ambiguous effect in which the contrast for false sentences was not significant, but for true sentences there was a negative effect of stepsize (t (1,28) = -3.93). This would indicate that items closer together in the list were actually easier to discriminate than those with greater ordinal separation. Besides being totally contrary to intuition for this sort of a task, this result was the reverse of all previously-reported findings (Potts, *et al.*, 1978).

If we recall that the List A average reaction time was approximately 150 to 200 msec. slower than accounted for by the quick-response estimates, it becomes apparent from Table 3 that pairs from List A could bias a contrast by virtue of the reaction-time "advantage." By the necessary structure of the contrasts, the List A "advantage" may have biased the semantic distance contrast toward significance, and the stepsize contrast away from significance. It would have had no effect on the ordinal position evaluation, as no pairs from List A are included in that contrast. In order to verify the obtained results, a second set of contrasts was performed using scores adjusted for each subject's individual mean reaction time. This had not been chosen as the initial adjustment measure because it effectively obliterates list differences; however, it provides the most conservative assessment of semantic distance and stepsize effects.

There is a crossover in the appropriateness of the two forms of score standardization, as is indicated in the column headings for Table 4. The anchor adjustment method was "too conservative" for the stepsize evaluation, biasing the contrast against significance. For the semantic distance evaluation, however, adjusting for subject means (including the "extra" List A RT) is the more conservative measure. The means adjustment (removing list effects) could artificially remove a real reaction time difference for the semantically closer items of List A.

Results of the "means-adjusted" contrasts were as before, except that the "negative effect of stepsize" disappeared--it was obviously a spurious result. Examining the individual pairings in Table 4 shows that 3 of the 4 comparisons were in the predicted direction, but the greatest magnitude in these differences is only 85 msec. Effects in the semantic evaluation were often double that magnitude. Semantic distance remained significant ($\underline{t}$ (1,28) = 3.23, true pairs; $\underline{t}$ (1,28) = 2.93, false pairs) even in this conservative test, and no effect of stepsize or ordinal position was statistically evident.

CHAPTER IV

DISCUSSION

Ordinal properties of items in naturally ordered lists have no effect on the difficulty of performing memorial comparisons of those items. When semantic distance, ordinal separation and serial position were totally unconfounded in the comparative judgement of object sizes, only semantic distance was found to have a significant effect on reaction time. This was found in a repeated test paradigm using a finite set of stimulus items. It will be argued below that these results firmly establish the necessity for a mode of memorial comparison in which analog relationships are not only stored in memory, but reflected in the information we use to make comparative decisions.

Although the present results do not rule out the use of a linear array for decision-making in some comparative tasks, they do suggest that data patterns previously accepted as evidence for ordinal effects should be examined in more detail. Data from this experiment, plotted in the standard fashion, showed patterns which have commonly been interpreted as evidence of serial position and ordinal separation factors systematically affecting reaction times. Many researchers (Moyer and Bayer, 1976; McKinley, 1975; Banks, 1977; Woocher, Glass, and Holyoak, 1978) have interpreted serial position functions, in particular, as evidence of the use of an internalized linear array. In some cases, they have also been the basis for the proposal of a scanning process. While linear arrays almost surely form the data base for some memorial comparison tasks, their construction and use may not be as common as has been claimed.

In the present task, subjects were exposed to the same seven stimulus items repeatedly over the course of two days. Apart from the pretest ordering and the practice trials at the beginning of the day and before each block, a subject made a comparative decision about any one item against the others in the list 96 times per day! If subjects did not form and use a linear "scaffold" in this situation, and they did not, we certainly must be cautious in proposing that such scaffolds are likely to be used in other circumstances. One probable exception is the case of experimentally taught orderings, especially if the orderings are arbitrary and relatively meaningless outside the experimental context. In such a case, there seem to be few reasonable ways for a subject to efficiently encode and memorize the trained relationships. Even in such cases as these, it appears to be imperative to "double check" qualitative analyses with quantitative evaluations (e.g., Woocher, Glass, and Holyoak, 1978). At the very least, we must reexamine the relationship between processes of retrieval and comparison in tasks using orderings learned within the experiment and those using orderings based on pre-experimental knowledge; the correspondence may be more tenuous than we had presumed.

The present results also suggest some specifications and/or modifications of the long-term data structures and related processes for the reference point and semantic coding models.

The lack of evidence for an effect of serial position of items in the list has direct implications for the reference point models as described by Jamieson and Petrusic (1975) and Holyoak (1978). It might be assumed that the end-anchors for the lists would also serve as the natural reference points for computing discrepancy ratios; had this been in fact true, however, it would have produced a negative effect of serial position for the selected pairs in which it was possible to evaluate the effect independently. The identical items in Lists B and C would have been evaluated against a smaller end-term in List B than in List C, giving the latter comparison the reaction time advantage. This is exactly the reverse of the prediction made in terms of ordinal position. Since there was no effect, in either direction, of serial position for these pairs, the end term could not have served as the reference point. However, if a consistent reference point outside the list were selected, identical pairs in the two lists would have produced identical discrepancy ratios, regardless of the ordinal position of the pairs. The most interesting aspect of this interpretation derives from the fact that list was a between-subject variable; the implication is that different subjects selected similar reference points. There is reason to believe that certain "typical" representations in memory may serve as ideal anchor points. Rosch and her colleagues (Rosch, 1975a, 1975b; Rosch, Mervis, Gray, Johnson, and Boyes-Braem, 1976) have presented the hypothesis that natural categories have prototypical examplars which appear with consistency across subjects, even cultures. We could additionally suggest that very large categories (such as "large things") may have prototypical exemplars of the extremes as well as of the central tendencies (or most overlapping attributes, or whatever). Dimensions themselves might act as categories and demonstrate the characteristics. The concept of an "ideal" reference point also coincides with the findings of Audley and Wallis (1964). They found a congruity effect which was nearly symmetrical when the background illumination was moderate; but when the background was very light or very dark, the general advantage switched to "darker" or "lighter" judgements. The light background may have made the ideal light reference point less efficient and vice versa. The concept of ideal reference representations is intriguing enough to merit further investigation.

But we suggested modification and specification of both model classes. The present study allows consideration of the semantic coding model on several points. First, as previously mentioned, decisions made in this task apparently were not mediated by a temporary data base structure. Data structure searches which would have produced serial position effects were definitely not evident in this task. It is possible, of course, that a scaffold was used just to "hold" information in active memory in order to provide easy access, but that no characteristics of this storage were used to compute a decision. If analog quantities were directly accessed from a scaffold, and then compared, this would be tantamount to a perceptual comparison, e.g., Jamieson and Petrusic's (1975) model (given the necessary additions to account for congruity). It is hard to see how a code could be generated from a scaffold without referring to at least the ordinal relationships which are represented in it. But if ordinal relationships were examined, at least a stepsize effect as found in transitive inference studies would be predicted. One was not found, and it will be argued below that subjects were not engaging in transitive inference. It appears safe to suppose that more permanent semantic memory was accessed to perform this task.

The second specification of the semantic coding model concerns the availability principle and the search mechanism which generates appropriate categorial codes for the stimuli. Banks (1977) described one likely heuristic as a search for a third item which can describe the relationship between the other two through transitive inference (Riley, 1976). For example, if the comparative decision were between A and C, we would search memory to find the relationships A > B and B > C, then by inference decide that A > C. The more ordinal steps (items) between the items compared, the greater the number of items which could be used to make a transitive inference; therefore, the transitive inference search in the present task would predict an effect of stepsize (increased step => decreased RT), which was not found. A transitive inference should have been easy to perform: the "item between" was provided within the context of the task itself. Even if subjects were not actively forming and using listings, priming or availability ("activation" in memory) of the item is represented as a magnitude rather than by ordinal indicators. We might then compare these magnitude estimates in terms of the third item. With a bit of reflection, it becomes clear that this heuristic being proposed for the semantic coding model bears a striking resemblance to the reference point model! If we can accept the proposition that this distance-to-a-third-item heuristic is viable as a semantic coding explanation of performance in the comparative judgement task, at least three questions remain: 1) Can we discriminate this heuristic and the reference point model? 2) Why might we use reference points? 3) Are they feasible in terms of any more global concepts of memory?

As Holyoak (1978) has noted, the distance ratio measure is sensitive both to the sum of the distances (actually, to each of the separate distances, which is assumed to be equivalent) and to the difference between them. So it is very difficult to discover whether "distance" relative to the reference point affects the generation or comparison stages or both, at least for the reference point model. According to that model (as clarified by Holyoak, 1978), calculation of the distances to the reference point occurs in the generation stage, and the ratio is "set up" and estimated in the comparison stage. Remember, however, that we have assumed a continuous comparison process on these analog values. The most clearly examined possibility for this process is the stochastic sampling procedure proposed by Buckley and Gillman (1974); a counter is incremented or decremented after each sampling estimate of the ratio is derived. If the counter does not pass a criterion value, another sample is taken. The process could require many repeated cycles through the generate/compare process, and thus it is unlikely that we could experimentally separate the two processes. Were we able to separate the processes, we might try to discover whether the comparison stage alone reflected analog values of the stimuli. Banks (1977) predicts that all analog effects occur prior to this code-comparison component of the semantic coding model.

The other opportunity for differentiating the models seems to lie in their different account of the congruity effect. The semantic coding model predicts the congruity effect by means of a conflict between the linguistic comparison codes for the stimuli and that for the instructions. The reference point model attributes the effect to subjective differences in the actual comparison of magnitudes as computed from one or the other "polar" reference points. A means may be developed in the future for distinguishing between these.

One possible basis for the use of reference points has already been discussed. Our concepts may be organized such that each attribute or category has a "best examplar" and it may be especially easy to retrieve these from memory to use for any number of purposes including as reference points for estimating continuous attributes. Secondly, it would in many ways seem efficient in terms of the long-term memory load to avoid storing a whole range of possible attribute values with each representative that we have in memory. Walker (1975) has already produced evidence that discrete attribute value information on at least physical properties is not stored (or not the only thing stored). Finally, some aspect of the comparative judgement task itself might predispose subjects to thinking in terms of extreme or polar examples. This could be easily checked by searching for evidence of reference points in other tasks where the questions and stimulus variables are more diverse. Rosch, for example (Rosch, Simpson, and Miller, 1976), has reported some similar effects in the acquisition of prototypical exemplars.

The concepts embodied in reference point interpretations are quite compatible with several global concepts of memory. Reference point concepts of magnitude and dimensional knowledge are essentially context-dependent in that the context may determine the selection of the reference point or even the form of the magnitude information retrieved (Holyoak, 1978). Holographic models of memory (Cavanagh, 1972, 1976) assume that exciting the memory representation in a particular manner may obtain very different results from exciting it in another. Some memory representations may be responsive to only a few or one form of excitation, and the information retrievable would be correspondingly limited. John (1967) has formalized this type of a memory model in neural terms. Another possibility is that memories may be stored in a primarily episodic (Tulving, 1972; Watkins and Tulving, 1976) form; this would be consistent with many notions of neural activation and retention (Hebb, 1949). If there are certain commonalities among the different episodes, a common excitation pattern might activate a set of dimensions from several episodes or a set of activity patterns of any type which have occurred in a common context. A pattern which is easily activated in many contexts or which provides the context for many other patterns might be equivalent to a reference point. John (1967) describes the neural record, or memory, as a transient pattern. In order for this transient pattern to be interpreted, it must occur over a specific underlayment of excitation. If the referent (context) is not activated, the information is still stored, but is not "available" for processing. Perhaps this is the parallel to the means by which the use of reference points allows us to retain inconceivable quantities of information and yet have only particular portions of that knowledge available to us at any particular point in time and usually only relative to a certain context. The information goes in in a "garbage pail" fashion (Landauer, 1975) and is retrieved by virtue of its commonalities with other episodes. The abstractive nature of memory would be an almost incidental result of such a system.

However we represent individual instances in memory, we are able to compare them on any single dimension as abstract wholistic concepts. It is not necessary that we inspect internalized versions of perceptual experience itself. But we do have the continuous, analog information available from perceptual (and perhaps conceptual) experience included in the memory representation and we do utilize analog relationships in performing memorial comparison.

FOOTNOTES

1. In this paper, _dimension_ and _attribute_ will be used interchangeably. However, in general _dimension_ will refer to the continuum along which an attribute may vary, and _attribute_ will be used when referring to a particular value on a dimension. These values may be numerical (2 tons) or ordinal (large +). We will not consider dimensions with nominal values (male/female) in this paper.
2. _Analog_ here is used in the sense of "not digital." Especially, not numerical or binary, but including anything of continuous or non-discrete character. This might encompass graphic forms, but is not limited to them. Kosslyn (1975) has suggested _undifferentiated_ as a useful designation; there are an infinite number of points on an undifferentiated dimension, and each of them has meaning.
3. This second criterion must be applied with discretion. It is recognized that believableness can be affected by many irrelevant factors including consistency with one's political views (cf. Chomsky, 1959), taking a flattering or unflattering view of

mankind (cf. Bateson, 1972), and consistency with common folklore (cf. Rosen, 1968). Even the apparently straightforward requirement of parsimony has been contested (e.g., Minsky, 1975; Wicklegren, 1976) as far too restrictive for models of such complex behaviors as human thought. Nonetheless, selecting and pursuing only the more natural and elegant of the myriad of available theories facilitates empirical evaluation, communication, and discussion and thus more directly benefits creative and productive scientific effort.

To take this position, we must believe that true anomalies will consistently recur and that any essential details ignored in selecting unadorned models will therefore eventually undermine the plausibility of those models.

4. Second-order isomorphism is a concept proposed by Shepard and Chipman (1970); while there may or may not be direct structural resemblance between an individual representation in memory and the actual object, they propose an isomorphism between the relations among external objects and the relations among their corresponding internal representations. In other words, "whatever neurophysiological events

are taking place while one is merely _imagining_ the external process in question--these events have much in common with the internal events that occur when one is actually _perceiving_ the external process itself" (Shepard and Feng, 1972).

5. _Image-processing models_ have been referred to as _analog models_ (especially by Kosslyn and his colleagues, e.g., Kosslyn _et al._, 1977). The term used by Banks (1977) has been selected for use in this paper in order to clarify the fact that there are several analog models which do not require reference to an internal representation which is an "analog" to perception, but only assume the use of a continuous representation of some kind. Primarily, the limited sense of analog only requires that interval or ratio scale properties of the perceptual continuum be preserved, while Kosslyn's interpretation requires that we be able to rerepresent the perception in memory.

6. Time to make a judgement is assumed to depend specifically on the difference between the ratio computed and a set criterion. The criterion is assumed to be one in the case of unbiased decisions (vide Jamieson and Petrusic, 1975).

7. Size may not be a unitary dimension for real objects, but might refer to length, width, thickness, volume, or less obvious qualities. Nonetheless, in multidimensional scalings (e.g., Henley, 1969) of animals, objects, and even countries or states, a dimension which is most readily interpreted as "size" frequently emerges. This appears to be reflected in natural language, as we can frequently be heard to make remarks such as, "Oh, his house is bigger than ours" when certainly we are speaking not of the length, height, or even volume of the house, but rather of general impressions on a "largeness" scale. Subjects evidenced no distress when requested to "order these objects by size" (in the present experiment as well as that of McKinley, 1975). For the present experiment especially, since a single master list of items was used and the necessity for relying on a scaling of the items was thus avoided, it was only essential that the selected "size" ordering be consistently and naturally replicated by all subjects.

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APPENDIX

Analysis of variance of mean reaction times

(four factor - collapsed across hand) *indicates $p < .05$

Source	d.f.	F	M.S. Error
List	3,28	3.92	7687148.297 *
Day	1,28	121.31	1588937.376 *
D x L	3,28	1.03	1588937.376
Truth	1,28	136.85	92502.135 *
T x L	3,28	.19	92502.135
D x T	1,28	12.41	46713.989 *
D x T x L	3,28	.79	46713.989
Pair	20,560	52.33	96624.614 *
P x L	60,560	2.47	96624.614 *
D x P	20,560	2.16	41121.554 *
D x P x L	60,560	1.09	41121.554
T x P	20,560	44.59	48142.619 *
T x P x L	60,560	2.44	48142.619 *
D x T x P	20,560	2.79	31515.787 *
D x T x P x L	60,560	1.30	31515.787