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LA THÈSE A ÉTÉ
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TOWARDS A DEVELOPMENTAL MODEL FOR SAME DIFFERENT JUDGMENTS

by

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Thesis presented to the School of Graduate Studies and Research
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ABSTRACT

In the field of human perception and performance, several theorists have developed different models to account for the process by which discrimination judgments involving multidimensional stimuli are made. In 1969, Donald Bamber proposed a two-process model--subjects using one process to decide whether two multidimensional stimuli are the same, another process in deciding that two stimuli differ. In an experiment using adult subjects in a discrimination task in which the stimuli ~~varied~~ along two to four dimensions, he claimed (a) same judgments were made after a parallel process of comparison, (b) different judgments were made after a serial self-terminating process of comparison. In fitting this model to the different judgments, Bamber made the important assumption that b_s , the processing time for a same decision on a single dimension, equals b_d , the processing time for a different decision on a single dimension.

In the present article, formal predictions were mathematically derived from Bamber's original serial self-terminating model and for the parallel and serial self-terminating models arising from a modification of Bamber's original model. These predictions were used to determine (a) whether subjects process stimuli according to Bamber's two-process model when stimuli are allowed to vary along ~~more~~ more than four dimensions, (b) whether children process stimuli according to the same model as adults.

In the present study, the reaction times of 80 young children (5 - 6 years), 80 older children (11 - 12 years), and 80 adults were measured in a task which required the subjects to indicate whether two simultaneously

presented coloured geometric forms were the same or different. According to the formal predictions from the modified serial self-terminating model (a) same reaction times should increase quadratically as the number of possible differences increases, (b) reaction times for different decisions with all differences present should also increase quadratically as the number of possible differences increases, and (c) whenever $b_s \leq b_d$, same reaction times should be faster than reaction times for different decisions with only one difference present. Similarly, formal predictions from the parallel models would require reaction times for different judgments with all differences present to be equal to reaction times for difference judgments with only one of the possible differences present.

The results of the present study indicated that predictions from the serial self-terminating model were confirmed not only for adults but for children suggesting uniformity of process over age. Furthermore, these results indicate that young children are able to process multi-dimensional stimuli dimension by dimension in accord with findings based on concept learning tasks.

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CHAPTER I

Introduction

An intelligent organism must be able to detect sameness and difference in order to react appropriately to its environment. At times, the detection even of very subtle differences such as those between an edible field mushroom and a "Deadly Angel" may be essential to survival. Indeed, an individual's "exactness of judgment" and "clearness of reason" are determined by his ability "to distinguish one thing from another where there is but the least difference". (Locke, 1960, Bk ii, Ch. XI, sec. 12) According to Boring (1963, p. 338), "The ability to discriminate is the criterion of mind, of consciousness, of knowing. The fact is that all the soluble problems of psychology can be reduced to problems of differentiated reaction if one wants so to reduce them."

To simplify and to make sense of the perceptual world, the individual attempts to detect sameness. As William James (1890, p. 459) said, "The sense of sameness is the very keel and backbone of our thinking." Recognition of a person or object as identical with one previously perceived brings order to the confusion of our environment. "The mind makes use of this notion of sameness and if deprived of it would have a different structure from what it has" (James, 1890, p. 460). The ability to differentiate sameness from difference is so elementary that the detection of identity and its converse, the detection of difference, became the basis for many psychological investigations.

While the detection of sameness and difference was the basis of

philosophical and psychological discussion and debate from the time of Locke, scientific study of the processes involved began with psychophysical experiments in the late nineteenth century. Early psychological investigations into the accuracy of human judgments of magnitudes were seeking quantitative estimates of the amount of physical difference required in various situations to bring about a judgment of difference. From Weber's (1834) investigation of the muscle sense by means of weight lifting experiments emerged the discovery that the just noticeable difference between two weights is a constant ratio of the standard stimulus.¹ Fechner (1860) replicated and extended Weber's work in the measurement and detection of small differences, and in the process formulated "Weber's Law"--The just noticeable difference between two stimulus magnitudes is a certain constant ratio of the total magnitude. Psychophysical methods, such as "The Method of Average Error", "The Method of Limits" and "The Method of Paired Comparisons", which were developed by Fechner, served to direct the attention of psychology towards the use of scientific techniques for the study of sensory and perceptual processes.

In the evolution of psychology from the late nineteenth century to the present, the detection of sameness and difference has been a basic element of important paradigms in experimental psychology. In matching paradigms, the experimental subject must choose, from two or more stimulus objects, a stimulus identical to a standard stimulus.

¹The ratio is 1:40. A 41 gram weight would be required for the perception of difference from a 40 gram standard, but an 82 gram weight would be just noticeably different from a standard weight of 80 grams.

Many matching to sample experiments have been designed to determine whether child subjects of various ages prefer colour or form. Brian and Goodenough (1929) typically showed two objects that differed from a third either in form or in colour. The child subject was required to match this third with the one just like it. Until six years of age, children tended to choose the object which was the same colour. In contrast, older children preferred to choose the stimulus which was the same shape. Further experiments such as those by Huang (1945), Kagan and Lemkin (1961) and Gindes and Barten (1977) have served to confirm this finding and delineate the role of variables influencing the matching process more precisely.

In the early 1960's, investigators became interested in computer simulations of human decision making, including the ability to decide whether stimuli are the same or different. In this endeavour a primary goal was the developing of a computer programme to model the human organism's ability to recognize and classify printed material. These researchers believed that the design and analysis of such models would enable insight into the nature of human perception, thinking, and judgmental processes (e.g., Uhr, 1963; Selfridge and Neisser, 1963). In an early computer model of human decision making, Selfridge and Neisser (1963) required the computer to determine the identity of a given letter from a group of four possible letters A, V, H, and Y. To distinguish among these four letters, the computer was programmed to compare stimuli for three possible differences: a concavity above, a crossbar, and a vertical line.

One of the programmes developed required the three comparisons to

be made one by one, each comparison being completed before the next was begun (see Figure 1). According to this serial process of feature comparison, the incoming letter is first examined for a concavity above. If no concavity is found, the computer identifies the letter as "A". If a concavity is found, the letter is then examined for the presence of a crossbar. If a crossbar is found, the letter is identified as "H". If a crossbar is not found, the letter is examined for the presence of a vertical line. If no vertical line is found, the letter is identified as "V". If a vertical line is found, the letter is identified as "Y".

The second programme, developed by Selfridge and Neisser, requiring all three comparisons to be made at the same time, was a parallel process of comparison (see Figure 2). According to Selfridge and Neisser, it is possible, in parallel processing to think of each feature as being inspected by a little demon. After reaching a decision, the little demons all shout their answer to a decision making demon. Selfridge and Neisser named this parallel processing model "Pandemonium". In the parallel programme for the recognition of A, H, V and Y, the computer is programmed to respond with an H decision if all three features are found. The identification of A, V, and Y, however, is dependent upon the pattern of "Yes" and "No" responses as shown in Figure 2.

The concepts of a serial and parallel processing were also used by researchers such as Sternberg (1966). In his short term memory experiments Sternberg described the processes used by a subject searching for several previously determined target stimuli in a larger set. According to Sternberg, analyses of reaction times demonstrated that the search was serial and exhaustive. Thus a subject scanned in turn each stimulus of the larger

FIGURE 1

A Sequential Processing Programme for Distinguishing Between the Letters A, H, V & Y.

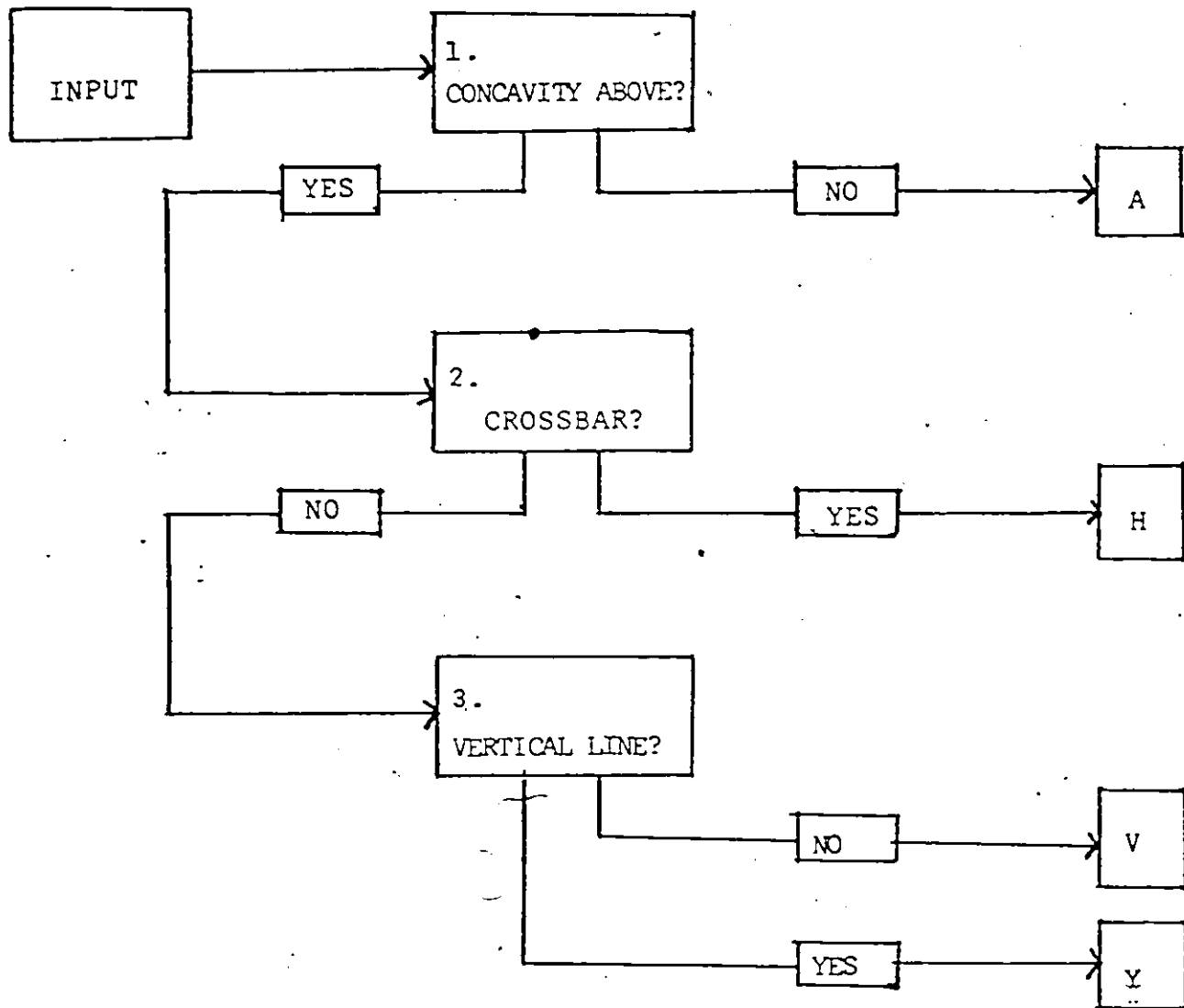
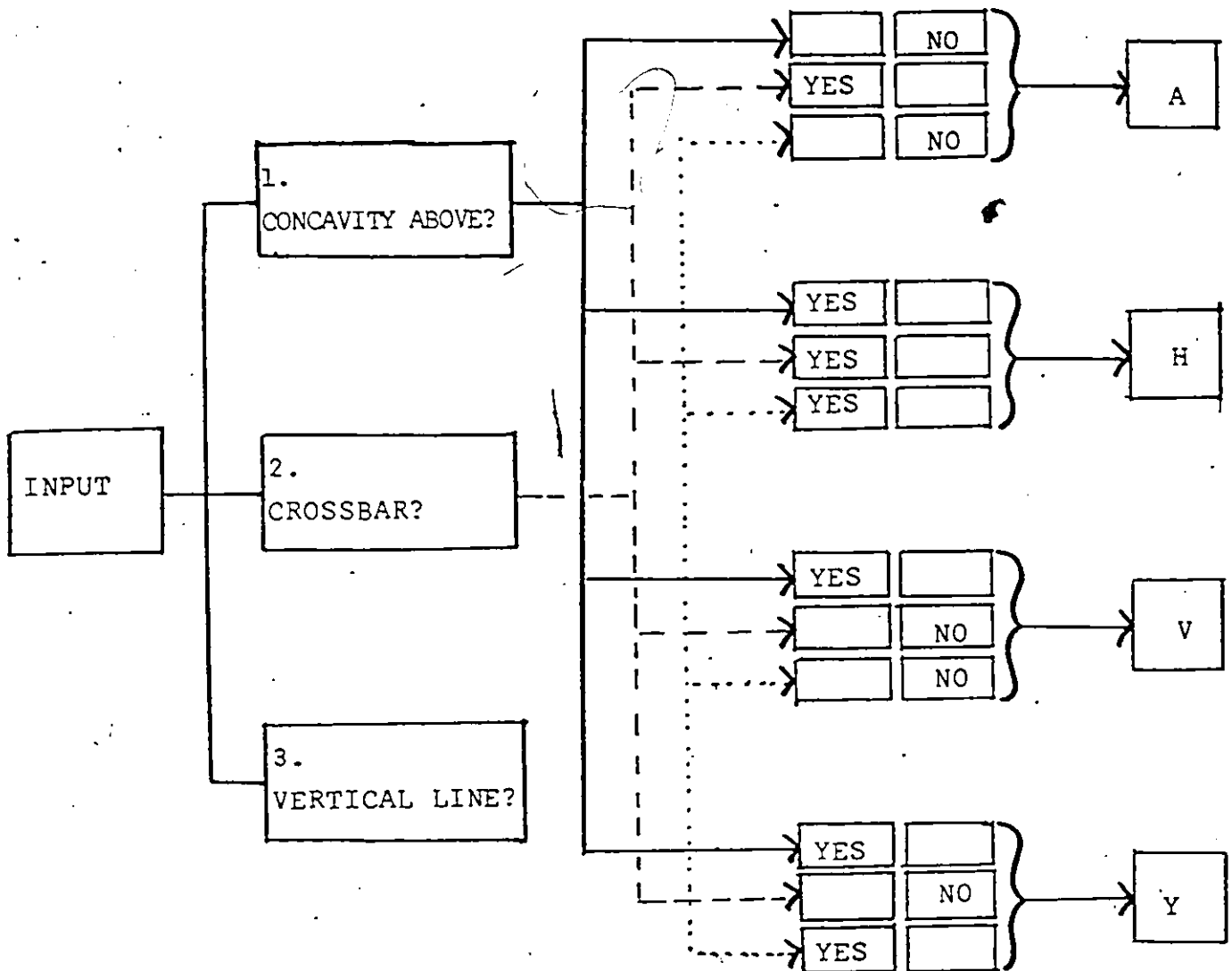


FIGURE 2

A Parallel Processing Programme for Distinguishing
Between the Letters A, H, V & Y.



set. If he found one of the target stimuli, he did not respond immediately but continued to scan until he had examined every stimulus object in the larger set. If the search process had been self-terminating, the subject would have terminated search after discovery of a target stimulus.

CHAPTER II

The "Same-Different" Paradigm

One of the difficulties in trying to create computer programmes which could perform complex discriminations was that the process by which humans actually accomplish discriminations among multidimensional stimuli was not clear. To investigate the process by which humans judge whether two (or more) objects are identical or different, the "same-different" paradigm was developed. In an experiment utilizing this paradigm, two or more stimuli are presented either simultaneously or sequentially. If the stimulus objects are identical, the subject pushes a "same" button. If any difference among the stimulus objects is perceived, the subject pushes a "different" button. Reaction time is the measure of principal interest, although errors are also enumerated and analyzed. Predictions involving the relative reaction times of same and of different judgments can be generated from the distinction between self-terminating and exhaustive processing.

If subjects are comparing stimuli according to a self-terminating model, a same (S) decision would be given only after checking every possible attribute or dimension upon which a difference could occur. In contrast, a different (D) decision could be made as soon as a difference was found. For this reason the D decision would often be given before the stimulus was compared on every possible dimension of difference. Inevitably, this early termination of dimensional comparisons in D decisions would produce D reaction times which were shorter than S reaction times, ($D < S$).

In an exhaustive model, an S decision is given after every possible dimension has been compared. In exhaustive models, all possible dimensional comparisons are also made before a D decision is given. Comparison does not terminate as soon as a difference is found. For this reason, D reaction times should be equal to S reaction times if stimuli are compared according to an exhaustive model ($D = S$).

Similarly, predictions involving the relative reaction times among D judgments with varying numbers of differences actually present, could be generated from self-terminating and exhaustive models. If differences occurred on each possible dimension, (D^{ALL}), a difference would be detected after one comparison. If the comparison process were self-terminating, a D decision would immediately be given. If only one of the possible differences occurred, (D^1), this difference would not always be found after one-dimensional comparison. Therefore the self-terminating model would predict that D reaction time would be faster when all differences were present than when only one difference was present ($D^{ALL} < D^1$).

Exhaustive models, however, do not permit a D decision to be given as soon as a difference is found but require completion of comparison on all possible dimensions of difference. Thus stimuli with all differences present, and stimuli with only one difference present will require the same number of completed comparisons. For this reason, exhaustive models predict that D reaction times for stimuli with all differences present will equal D reaction times for stimuli with only one difference present ($D^{ALL} = D^1$).

A self-terminating process of comparison is being used when:

1. reaction time for S decisions is longer than reaction time for D

decisions ($S < D$), and

2. reaction time for D decisions for stimuli with all differences present is shorter than reaction time for D decisions when only one difference occurs between the stimuli ($D^{ALL} < D^1$).

The empirical results of Egeth's (1966) experiment demonstrated that reaction time for D judgments decreased as the number of dimensions with stimulus differences increased. Reaction time for D^{ALL} judgments was reliably shorter than reaction time for D^1 judgments. In this experiment, Egeth did not directly compare S reaction times to D reaction times because he believed the comparison was invalid due to confounding produced by his experimental procedures involving irrelevant dimensions. Nevertheless, he concluded that his results were best explained by a self-terminating process of comparison.

Nickerson (1965), however, did compare S reaction times to D reaction times, discovering that reaction time for D decisions was longer than reaction time for S decisions. A further experiment by Nickerson (1967) confirmed Egeth's (1966) findings with respect to the relationship among reaction times for D stimuli with varying numbers of differences present. As the reaction time for D decisions varied inversely with the number of differences actually present, Nickerson (1967) interpreted his empirical results for D decisions as evidence in favour of a self-terminating process of comparison. If the comparison process was self-terminating, however, S reaction times should be slower than D reaction times, even D^1 reaction

times.¹ Nickerson's (1967) results however, failed to support this prediction from the self-terminating model. Empirical results for S decisions indicated that S reaction times were a) faster than D¹ reaction times, b) slower than D^{ALL} reaction times. The search for a completely satisfactory explanation for the "fast sames" began with Nickerson (1967) and continues today.

To explain the phenomenon of fast S reaction times, Bamber (1969) tested the accuracy of quantitative predictions from the serial self-terminating model, using letter groups as stimuli.

These quantitative predictions were derived using the following reasoning: As the model is self-terminating, the subject gives a D judgment immediately upon detection of a difference. Each stimulus will contain L letters, D of which are different. The position of the D letters varies randomly from trial to trial. The mean number of S comparisons processed prior to the first D comparison will be $(L - D)/(D + 1)$. Let b_s represent the processing time for an S judgment while b_d represents the processing time for a D judgment. The mean time for processing a stimulus before deciding it is different then becomes $[(L - d)/(D + 1)] b_s + b_d$. Let h_s represent the mean neural transmission time between retina and brain and between brain and muscles for S decisions and h_d represent the mean neural transmission time for D decisions. The mean reaction time for D judgments then becomes

¹Before an S judgment can be given, the stimulus must be examined on every possible dimension of difference. For a D¹ judgment, the difference will sometimes be found before all dimensions are compared. If the comparison process were self-terminating, a D decision could immediately be given. Thus early termination of processing for some D¹ decisions will result in shorter average reaction times for these stimuli than for stimuli resulting in an S decision.

$$Rtd = h_d + \left(\frac{L - D}{D + 1} \right) b_s + b_d \quad (1).$$

If the stimulus is the same and contains L letters, each letter must be examined before an S decision can be given. Therefore, the mean reaction time for S decisions becomes

$$RTs = h_s + Lb_s \quad (2).$$

$$\text{Let } a = h_d + b_d$$

$$e = (h_s - h_d) + (b_s - b_d)$$

$$\text{Then Eq. 1 becomes } Rtd = a + \left(\frac{L - D}{D + 1} \right) b_s$$

$$\text{and Eq. 2 becomes } Rts = a + (L - 1) b_s + e.$$

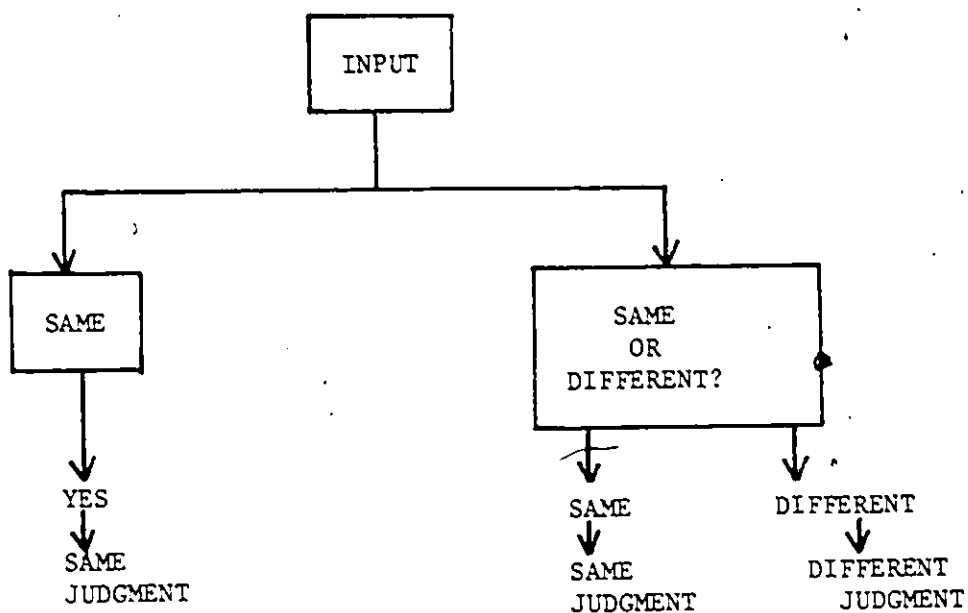
The above predictions are then fitted to the experimental data.

In Bamber's experimental data, S reaction times were faster than D reaction times. When all differences were present, D reaction times were shorter than D reaction times when only one difference was present. Thus comparison of S reaction time to D reaction time appeared to indicate subjects were not processing stimuli according to a self-terminating model. To resolve this contradiction, Bamber developed a two-process model which can be depicted in a flow chart such as that in Figure 3.

Bamber's two-process model postulates two processors which make stimulus comparisons simultaneously. One processor, labelled the "identity reporter", uses a fast, inaccurate parallel process of comparison to determine whether all stimuli are the same. As soon as the identity reporter discovers that the stimuli are the same, an S judgment is given. The second processor, called the "serial processor", uses a slow but accurate serial

FIGURE 3

A Flow Chart Depiction of a Two-Process Model for Complex Discrimination in "Same-Different" Judgments Proposed by Bamber.



process of comparison to determine whether the stimuli are the same or different. If a difference is discovered, a D judgment is given. If no difference is discovered, an S judgment is emitted but not acted upon. Since the identity reporter has found the sameness much more quickly, an S judgment has already been made. Therefore, the S judgment given by the serial processor is redundant.

Essentially, in the two-process model, S decision times are faster than D decision times because the parallel method of processing for S decisions is faster than the serial method of processing for D decisions.¹

Research Testing the Two-Process Model

In 1972, Bamber first tested the validity of his two-process model. He used the distinction between nominally and physically identical stimuli first used in "same-different" judgments by Posner and Mitchell (1967). As defined by these experimenters, physical identity requires that the stimuli have exactly the same physical appearance e.g. "B" and "B". In contrast, nominal identity only requires that the stimuli have the same name. Therefore, "B" and "b" would be nominally identical because they have the same name but are not physically identical in their appearance. "B" and "A", however, would be neither physically nor nominally identical as neither their appearance nor their name is the same. Posner and Mitchell (1967) found faster reaction times for "same-different" judgments using physically identical stimuli than for judgments where the stimuli

¹In simple parallel models the comparison process is shorter because all dimensions are compared at the same time. Serial comparison is slower because comparison must be complete on each dimension before comparison on the next dimension begins.

were nominally identical. Eichelman (1970 a & b) also found that reaction times were shorter for physically identical stimuli than for nominally identical stimuli.

Posner, Boies, Eichelman and Taylor (1969) compared "same-different" reaction times for physically identical stimuli to those for nominally identical stimuli. Again, reaction times for physically identical stimuli were faster. These experimenters, however, were also able to show that the reaction time advantage of physically identical stimuli was reduced with successively presented stimuli, as the interval between presentation of the stimulus objects increased.

Beller (1970) replicated Posner and Mitchell's (1967) results. When physically identical stimuli were used, Beller maintained comparison was according to Neisser's (1967, p. 10) preattentive processing, which was fast, inaccurate and parallel. Nominally identical stimuli were compared according to a focal attentive (Neisser, 1967, p. 10) process which was slower, more deliberate and serial.

Bamber (1972) used this distinction between nominal and physical identity, hypothesizing that the fast identity reporter could process only physically identical stimuli. For physically identical stimuli, therefore, the fast identity reporter would process S decisions. This parallel processing would make S reaction times shorter than D reaction times. For nominally identical stimuli, however, the slow serial processor would process both S and D decisions. This serial processing would produce S reaction times of the same length as D reaction times. This hypothesis was not substantiated by Bamber's (1972) empirical results. S decision times were shorter than D decision times for both nominally

and physically identical stimuli. From this, Bamber concluded that either the two-process model was incorrect or that the identity reporter could handle both hominally and physically identical stimuli. Bamber himself preferred the latter explanation.

In 1969, Hawkins also investigated the processing of multidimensional stimuli in "same-different" judgments. Using geometrical stimuli which were allowed to vary in colour, form and/or size, Hawkins decided his empirical results were best explained by a parallel self terminating model. Results of this experiment, however, were influenced by a relatively difficult discrimination along the size dimension and use of different subjects for S decisions and for D decisions.¹

Krueger (1970) investigated the effect of bracketing lines on "same-different" judgments. In this study, the two letters comprising each stimulus could be bracketed by vertical lines of varying height.² The height of the bracketing lines was found to affect D judgments but not S judgments. This was interpreted as support for Bamber's (1969) two-process model. Krueger (1970) maintained that S reaction times were not affected by bracketing lines because S judgments were made by simple image matching; i.e., fast identity reporting. In contrast, D judgments were

¹ Results from two subjects were used for S reaction times while D reaction times were obtained from two other subjects. If absolute reaction times for S and for D judgments vary widely between subjects, then obtained findings could occur easily. Examination of empirical results, Bamber (1969, 1972), Jansen (1974), Hawkins (1969) and the present investigation suggests that such differences in absolute reaction times among subjects are possible.

² Examples of Krueger's stimuli

'A' x 'K' |A| x |K| |A| x |K|

affected by bracketing lines because processing involved a slower serial process of letter identification and naming.

In a further test of the two-process model Krueger (1973) used letters bracketed with irrelevant material in a symmetrical or asymmetrical fashion. In the first experiment of this study, the brackets consisted of single lines which could appear below either one or both of the two letters comprising the stimulus.¹ In the second experiment, brackets composed of = or signs or both appeared above and below each of the two stimulus letters.² Reaction times increased more for S judgments than for D judgments, when asymmetrical irrelevant material was used. A greater increase in error rates for S judgments also occurred with the addition of asymmetrical irrelevant material. Krueger explained his results in terms of the Bamber two-process model. S judgments were made after a fast crude parallel process of comparison before the addition of asymmetrical irrelevant material. D judgments, in contrast, were made after a slow sequential process of comparison. Addition of the asymmetrical irrelevant material affected the speed and accuracy of the parallel processing

¹ Examples of Krueger's (1973) stimuli for the first experiment.

A B ; A B ; A B ; A B

² Examples of Krueger's (1973) stimuli for the second experiment

= =
A B
= =
+ =
A B
+ =

+ +
A B
+ +
= +
A B
= +

used for S judgments more than that of the serial processing used for D judgments.

Tversky (1969) was interested in pictorial and verbal encoding in the "same-different" paradigm. Schematic faces, each with a name, were used as stimuli. In a pre-experimental training session, subjects thoroughly learned to associate the appropriate name with each face. On experimental trials two stimuli were exposed. For each trial both stimuli could be faces, both could be names, or a name and a face could appear. The important experimental manipulation was the probability that the two stimulus objects were of the same modality. When the modality of the second stimulus was not expected, subjects took longer to reach a decision. Tversky suggested this longer time was used by the subject to convert the second stimulus to the modality of the first before a decision was made.

Tversky's data also indicated that D decisions were faster when all possible attributes were different than when only one attribute was different. This was interpreted as evidence for serial self terminating comparison for D judgments as required by Bamber's (1969) two-process model.

Jansen (1974) used both child and adult subjects to test the generality of Bamber's (1969) two-process model. In formulating her hypotheses, Jansen utilized the distinction between "easy" and "difficult" discriminations employed by Nickerson (1967, 1969).

Subjects use a relatively lax criterion for judging stimulus identity, Nickerson (1967, 1969) stated, when differences on each dimension

are "easy" to detect.¹ When the discrimination was "easy", stimuli might not be compared on every dimension before the judgment was given. Thus Nickerson (1967, 1969) predicted S judgments would be faster than D judgments under "easy" conditions. As the comparisons would often be incomplete, Nickerson maintained, errors would be frequent. This position was supported by Corballis, Lieberman and Bindra (1968) who maintained the S reaction times in their study were faster than the D reaction times because differences between stimuli were easy to discriminate.

When stimuli differ "only minutely" (Nickerson, 1967, p. 553), subjects use a much stricter criterion for judging sameness and difference. In such discriminations, a comparison on each dimension is made. This process, Nickerson states, is both slower and more accurate. Only after all possible comparisons are made, can S judgments be given in such "difficult" discriminations. In contrast, D decisions can be given immediately after the first difference is found. For "difficult" decisions, therefore, D reaction times are shorter than S reaction times.²

¹An "easy discrimination" was defined by Nickerson as one in which "the smallest difference that he (the subject) will have to judge will be large enough to be readily discriminated". (Nickerson, 1967, p. 553). This explanation was further illustrated by reference to his own stimuli--simple geometric shapes different in form, size and/or colour.

²Although Nickerson (1967, 1969) refers to Egeth (1966), he does not use Egeth's distinction between serial and parallel processing. When Nickerson refers to a fast error-prone process of comparison, however, he could well be describing a situation which Egeth (1966) would describe as parallel processing. Similarly, Nickerson's slow accurate type of processing could be analogous to serial processing. Thus fast S reaction times are found when subjects use a fast error-prone type of comparison (like parallel processing). In contrast, slow S reaction times are found when subjects use a slow accurate form of comparison (like serial processing).

Entus and Bindra (1970), using circular patches of light, also concluded that relative reaction times for "same-different" judgments were determined by the difficulty of the discrimination. In their experiment, S reaction times were faster than D reaction times when the discrimination was easy. D reaction times were faster, however, with more difficult discriminations.

Nickerson (1967, 1969) maintained that, subjects compare stimuli according to a fast parallel model when the discrimination is easy. Thus, Jansen (1974) reasoned, fast S reaction times should occur when the discrimination is "easy". Fast S reaction times would indicate parallel processing by Bamber's (1969) identity reporter. Jansen (1974) further hypothesized that a discrimination which was easy for an adult would not be easy for a young (5 year old) child. If the discriminations were difficult, S reaction times would be slower than D reaction times. This would indicate that children were not parallel processing and further, provide no support for the existence of Bamber's (1969) identity reporter in children.

Jansen's (1974) empirical results replicated results found with adult subjects by Grill (1971) and Corcoran (1967). Reaction times for S decisions in the adult control group (Jansen, 1974) were initially slower than D reaction times. S decision times, however, became faster than D decision times with sufficient practice. These results could have been interpreted as a switch from serial to parallel processing after sufficient practice. However, the child groups used by Jansen (1974) recorded S reaction times which were faster than D reaction times on all three test days. Thus child groups appeared to use parallel processing

without practice. Furthermore, examination of the D reaction times according to Egeth's (1966) models, indicated that subjects were processing stimuli according to a parallel self terminating distributed model. Thus all subjects (Jansen, 1974) appeared to use parallel processing for both S and D judgments. Jansen concluded that the data provided little support for Bamber's (1969) two-process model.

Bamber, Herder and Tidd (1975) tested the two-process model for both the usual "same-different" paradigm and a task they deemed analogous to "same-different" judgments. The usual "same-different" task is described by Bamber, Herder & Tidd (1975) as "conjunctive matching". In the "same-different" or "conjunctive matching" task, the subject answers "same" if the stimuli are the same on every possible dimension of difference. If one or more differences are found, the subjects responds with a D decision. The analogous task used by Bamber, Herder and Tidd (1975), was described as "disjunctive matching". In disjunctive matching the subjects responds "different" if the stimuli are different on every possible dimension of difference. If one or more comparison does not result in a difference, the subject responds with a "not different" decision. Thus in the conjunctive case, the S judgment results from an S decision on every point of comparison. In the disjunctive case, the D judgment results from a D decision on every point of comparison. Both such cases can be described as an "all" judgment. Similarly, in the conjunctive case, the D judgment results when one or more differences are found--that is the stimuli are not the same on all dimensions. In the disjunctive case, the "not different" decision occurs when the stimuli are not different on all dimensions. Both these latter cases can be described as "not all" judgments.

Bamber, Herder and Tidd (1975) used a task requiring subjects to compare two strings of letters. If each pair is different, the subject responds "no"--the "all" decision. If one (or more) pair is the same, the subject responds "yes"--the "not all" decision. The two strings of letters were never identical, therefore Bamber's (1969) identity reporter would not be utilized in this task. The reaction times for both the "yes" and the "no" decisions, therefore should be consistent with the serial of self terminating model.

The reaction times increased linearly as the number of possible differences increased, both for "yes" responses and for "no" responses. These findings were interpreted by the experimenters as evidence for the existence of the serial processor. The existence of the identity reporter was neither supported nor disproven in this study.

Silverman and Goldberg (1975) used a task similar to that of Bamber, Herder and Tidd (1975). It differed only in the use of number instead of letter strings. Silverman and Goldberg (1975) found, however, that reaction times increased linearly with the number of possible differences only for the disjunctive matching task. Since the reaction times did not increase linearly with the number of possible differences for the "same-different" task, Silverman and Goldberg (1975) interpreted these results as failure to support the existence of Bamber's (1969) serial processor. Again, the existence of the identity reporter was neither supported nor disproven by this study.

Alternatives for the Two-Process Model

Lockhead (1972) proposed an alternative to models employing either an analytic serial or a parallel process of comparison. In this model, the

stimulus is first perceived holistically, as a "blob", without comparison on individual dimensions. If a response can be given on the basis of general similarity, a decision is immediately given. If the information gained is insufficient¹ to reach an immediate decision, a series of glances is initiated, terminating when sufficient information has been received to make a decision possible.

This model differs from Bamber's (1969) two-process model in that the second serial form of comparison is initiated only after the first blob comparison fails to produce sufficient information to reach a decision. The initial "blob" stage of comparison also differs from Bamber's identity reporter in that "blob" processing does not involve comparison along several dimensions as does the parallel processing of the identity reporter. Although Lockhead (1972) did not test his model experimentally in the "same-different" paradigm, his concept of holistic processing has recently been utilized by other researchers in "same-different" experiments.

Recently, Miller (1978), focussing on the reliability of the currently popular two-model process model, examined the nature of the comparison process involved in D judgments. Previous experiments such as Bamber (1969, 1972, 1975) and Krueger (1970, 1973) had concluded that D judgments were made after a serial self terminating process of comparison. In Miller's (1978) experiment, the percentage of fast¹ responses to slides with one difference present (D^1) was compared to the percentage of fast responses to slides with two differences between stimuli (D^2). The percentage of fast D^2 reaction times was significantly more than would be

¹A fast reaction time was defined as a reaction time equal to or shorter than 400 m/sec.

predicted from examination of the percentage of fast D^1 reaction times. Since this relationship could not be predicted from any analytic model, Miller postulated a holistic model for D judgments.

Krueger (1978) was also interested in producing an effective explanation for faster S reaction times. In his model, Krueger assumes that subjects require one or more glances to process stimuli for "same-different" judgments. Comparison within each glance is holistic. However a series of glances is assumed to occur before enough information is obtained to provide a decision. This model further assumes that perceived differences are counted. Noise is said to distort the difference count, producing a low count for stimuli that are actually the same as well as increasing the count for stimuli that are different. If the difference count is above a criterion point, a D decision results. An S decision results from a difference count below a second criterion point. According to Krueger, noise is "more likely to make a same pair look different, than a different pair look same" (1978, p. 279). For this reason, subjects recheck different pairs. This rechecking results in slower reaction times.

Empirical Variables Related to "Same-Different" Judgments

Codability

Bindra, Donderi and Nishisato (1968) found codability had an important influence upon relative reaction times for S and D decisions. Their empirical results demonstrated fast S reaction times only for codable stimuli. Bindra, Donderi and Nishisato (1968) defined a codable stimulus as a stimulus, "the properties or attributes of which most Ss [can] categorize in absolute terms without reference to another (e.g. standard)

stimulus" (p. 129).

According to this definition, two colours used in a "same-different" study would be codable if each could be easily labelled. For example, a subject might label one stimulus "red" and another "blue". If the colour of a stimulus object could not be easily labelled, colour would not be codable. This would occur if stimuli appeared in various shades of red such that all shades used could be labelled "red". In this hypothetical situation, colour differences between the stimuli would be small but detectable and the exact two shades used for a particular stimulus pair would vary from trial to trial.

Practice

Grill (1972) demonstrated that practice had an important effect upon the relative reaction times for S and D judgments. Using adult subjects, Grill found that S reaction times were initially slower than D reaction times. This was interpreted as an indication that subjects were processing stimuli according to a serial model. After sufficient practice, however, subjects' reaction times for S decisions became shorter than their reaction times for D decisions. This was interpreted as an indication that subjects were able to process stimuli according to a parallel model after they had sufficient practice. Grill maintained that the improvement in reaction times was too large to be the result merely of faster serial processing. Corcoran (1967) also obtained an improvement in S reaction times relative to D reaction times as the number of trials increased. Again, this was interpreted as an indication of a switch from serial to parallel processing after sufficient practice.

Developmental Status of the Subject

A. Ability to Perceive Stimulus Differences

In any "same-different" experiment, reaction time consists of the time required a) to examine the stimulus dimensions along which differences may occur, b) to perceive those differences which occur (or the absence of difference on all dimensions), c) to judge that the stimulus objects are the same or different, and d) to perform the correct motor response. If the subjects are unable to perceive the differences on a particular dimension or dimensions, they will be unable to perform the task with the requisite degree of accuracy. Adult subjects have judged "same-different" stimuli with differences on a variety of dimensions (e.g. colour, form, size). Use of subjects other than adults would require some evidence that the ability to perceive differences remains intact. The development of a child's ability to detect sameness and difference along such dimensions as form, colour and size has been of interest since the late nineteenth century. Wherever a particular pattern of discrimination has been established for adults, the extent to which this pattern occurs at various age levels then becomes an important question.

The ability to perceive colour has been found to develop while children are very young. As early as 1888, Preyer studied the development of colour discrimination in young children. By the 112th week, he found that the child understood the concept "colour" and could distinguish yellow. Blue, however, was not reliably identified until the fourth year. Based

on their observation of fixation, grasping, and reaching responses, Marsden (1903), McDougall (1906-1908) and Valentine (1913-1914) concluded that infants with an age range of 6 weeks to 8 months could detect colour differences. By 1932, Staples established that chromatic sensations were experienced as early as the third month; while four colours could be distinguished by 12 months. Interest in the young child's ability to perceive colour differences has continued to the present. For example, Gaines and Little (1975) established that colour perception has the same behavioural response pattern across ages and skill with most errors occurring with reds and greens, least errors with yellows and oranges, and with blues and purples falling between these two extremes.

Visual acuity in young children has been found to be surprisingly well developed when compared to that of adults. Peckham (1933) maintained that visual acuity in 28 month old children was just as great as that of adults. Later, Fantz (1958, 1963) measured infant visual acuity, finding that the width of stripes which the infant could distinguish decreased rapidly during the first six months of life. Infants below one month of age could distinguish $1/8$ in stripes at 10 ft whereas $1/64$ in stripes at 10 ft could be distinguished by infants 6 months old.

According to Gellerman (1933) two year old children cannot only distinguish but remember simple shapes such as a square or triangle. Indeed, Ling (1942) was able to demonstrate that simple discrimination between blocks of different shapes was possible at six months of age. In a shape matching task, however, discrimination of shape differences was

found to improve from 4 to 8 years of age (Gibson et al, 1962). Similarly, the reaction time of child subjects identifying the "different" shape in a set of three improved between the ages of 5½ and 7 . (Rajalaksmi and Jeeves, 1963).

In contrast to early achievement of visual acuity and accurate perception of form and colour, the young child's ability to detect size differences appears to be affected by shape variables and number of size categories utilized. Stars, ellipses and triangles were judged larger than squares, rectangles, and circles of equal area by kindergarten subjects in an experiment by Peters (1927). For children, the sharp angles and greater linear distance between corner points of stars, ellipses, and triangles was said to enhance the apparent size. Children 40 months of age were able to discriminate between big and little in an experiment by Welch (1939). These children, however, were unable to judge accurately a middle-sized figure. The latter ability was acquired by 5 years of age (Meyer, 1940) or 9 years of age (Graham, Jackson, and Long, 1944, Vinake, 1951), the difference in findings being related apparently to differences in the magnitude of size differences to be discriminated. In contrast, Estes (1961) found no age differences in the cues used by subjects from kindergarten to college age when matching either identical or different shapes as to size. Use of such cues as altitude, area, and length of sides appeared to depend on configuration of the stimuli rather than age.

Thus, empirical results of experiments from the late nineteenth century to present appear to indicate that when children reach school

age, they are able to perceive differences in colour, shape, and size (small and large) with sufficient accuracy to permit "same-different" judgments with stimuli differing on these dimensions.

B. Stimulus Separability

Garner (1970, 1974) and Lockhead (1966, 1972) distinguish between dimensional combinations which are perceived as the conjunction of separate components, and those combinations which are perceived as integral, unitary wholes. Adult subjects have been found to perceive brightness and saturation as integral dimensions being unable to sort stimuli on the basis of brightness without being disrupted by variation in stimulus saturation. In contrast, adult subjects do not perceive the size of a circle and the angle of a radial line as integral. Sorting on the basis of circle size is not disrupted by variation in the angle of a radial line or vice versa.

Investigations of stimulus separability have suggested that some dimensions perceived as separable by adults and older children may be apprehended as integral by younger children. Evidence from the free classification paradigm first indicated that five year old children classified stimuli on the basis of perceived overall similarity whereas ten year old children tended to classify on the basis of dimensional relationships (Smith and Kemler, 1977). A further experiment (Kember and Smith, 1978) indicated that younger (five year old) children were sensitive to dimensional differences, as indicated by their use of dimensional descriptions. In contrast to the older children, however, the five year olds did not utilize dimensions for the sorting tasks. Kemler and Smith (1979) utilized colour and form as well as size and brightness in two

separate experiments involving a concept learning task. No evidence for developmental differences was found. Both five year old and ten year old children treated the dimensional combinations of form and colour and those of size and brightness as separate dimensions. The results of this experiment were interpreted by Kember and Smith as evidence for the sensitivity of young children to the dimensional structure of stimuli "under some conditions" (1979, p. 150).

In the "same-different" paradigm, a serial processing model requires the subject to attend to the stimulus dimension by dimension. If young children treat stimulus dimensions as integral while adults and older children treat them as separable, results obtained from young children's "same-different" judgments cannot be explained by the same processing model as those of adults.

Formal Predictions from Serial and Parallel Models for "Same-Different Judgments"

To determine whether subjects are processing "same-different" stimuli according to a parallel or a serial model, predictions from these models will be mathematically derived. Let b_s be the processing time for a same decision on a single stimulus dimension and b_d be the processing time for a different decision on a single stimulus dimension. The number of dimensions along which a stimulus may differ will be designated by L and the number of differences present will be identified as D . Reaction time for stimuli with three stimulus differences possible and three differences present, for example, will be denoted RT_{DDD} . Similarly, stimuli with two differences present will become RT_{SDD} , RT_{DSD} or RT_{DDS} depending

upon the order in which stimulus dimensions are interrogated. Let h be the mean time required for transmission of information from the retina to the brain and from the brain to the muscles.

A. Predictions from the Serial Self Terminating Model

According to Bamber's (1969) serial self terminating model, reaction times for D decisions are given by

$$RT_{\text{DIFFERENT}} = h + \frac{(L - D)}{(D + 1)} b_s + b_d \quad (1)$$

In the present report, an important modification of Bamber's model is proposed since there is strong evidence requiring the rejection of the constancy of b_s and b_d . In fact, according to Hyman (1952) and Egeth (1966), reaction time for a single dimensional comparison, either b_s or b_d , increases linearly with the increase in the amount of stimulation present. Thus, for the modified serial model, Equation 1 becomes

$$RT_{\text{DIFFERENT}} = h + l \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right] \quad (2)$$

where l is a linear component depending on L and $l \leq 1$. The predictions from this model, together with proofs now follow.

Prediction 1: When $L = D$ reaction time increases as L increases.

Proof: When $L = D$, Equation 2 predicts $RT_{\text{DIFFERENT}} = h + l \cdot b_d$. As L increases l increases. Equation 1, on the other hand, predicts $RT_{\text{DIFFERENT}} = h + b_d$ which is constant for all values of L . Bamber's empirical results (1972, p. 323, Figure 3) fit predictions from (2) but not from (1).

Prediction 2: From Equation 2, it is possible to generate the following prediction:

$$\frac{RT_{DSS} + RT_{SDS} + RT_{SSD}}{3} > RT_{DDD} \quad (\text{compare with Hawkins, 1969}).$$

Proof: When $L = 3$ and $D = 1$, Equation 2 becomes

$$\begin{aligned} RT_{\text{DIFFERENT}} &= h + 1 \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right] \\ &= h + 1 \left[\frac{(3 - 1)}{(1 + 1)} b_s + b_d \right] \\ &= h + 1 [b_s + b_d] \\ &= h + 1 b_s + 1 b_d \end{aligned}$$

When $L = 3$ and $D = 3$, Equation 2 becomes

$$\begin{aligned} RT_{\text{DIFFERENT}} &= h + 1 \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right] \\ &= h + 1 \left[\frac{(3 - 3)}{(3 + 1)} b_s + b_d \right] \\ &= h + 1 b_d \end{aligned}$$

$$h + 1 b_d < h + 1 b_s + 1 b_d \therefore RT_{DDD} < \frac{RT_{DSS} + RT_{SDS} + RT_{SSD}}{3}$$

It is evident from the proof that the result also holds for the original Bamber model. Available experimental evidence confirms this prediction (Bamber, 1969, p. 171, Figure 1).

Prediction 3: From Equation 2 it is also possible to generate the following prediction:

$$RT_D < RT_{DDD} \quad (\text{compare with Hawkins, 1969}).$$

Proof: When $L = 1$ and $D = 1$ Equation 2 becomes

$$\begin{aligned}
 RT_{\text{DIFFERENT}} &= h + 1 \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right] \\
 &= h + 1 \left[\frac{(1 - 1)}{(1 + 1)} b_s + b_d \right] \\
 &= h + 1_1 b_d
 \end{aligned}$$

When $L = 3$ and $D = 3$

$$\begin{aligned}
 RT_{\text{DIFFERENT}} &= h + 1 \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right] \\
 &= h + 1 \left[\frac{(3 - 3)}{(3 + 1)} b_s + b_d \right] \\
 &= h + 1_3 b_d
 \end{aligned}$$

However l increases as L increases. Therefore, $1_1 < 1_3$ where 1_3 is defined as l for subjects judging stimuli with a maximum of three differences and 1_1 is defined as l for subject groups judging stimuli with a maximum of one difference. Therefore,

$$h + 1_1 b_d < h + 1_3 b_d \text{ and } RT_D < RT_{\text{DDD}}.$$

Importantly, Prediction 3 distinguishes clearly the original Bamber (1969) model and the proposed modification. Bamber's results (1972, p. 323, Figure 3) support the proposed modification.

Prediction 4: From Equation 2 it is possible to generate the following prediction:

$$RT_{\text{DSS}} > RT_{\text{DDD}} \text{ (compare with Hawkins, 1969).}$$

Proof: When $L = 3$ and $D = 1$,

$$RT_{\text{DSS}} = h + 1 b_d. \text{ In a serial model, in which the order in which}$$

dimensions are compared, varies randomly from trial to trial, the difference might only be found after the second or third possible comparison.

Therefore

$$RT_{SDS} = h + 1 \cdot b_s + 1 \cdot b_d \quad \text{and} \quad RT_{SSD} = h + 2 \cdot 1 \cdot b_s + 1 \cdot b_d$$

The average of RT_{DDS} , RT_{SDS} and RT_{SSD} then becomes $h + 1 \cdot b_s + 1 \cdot b_d$. As

$$RT_{DDD} = h + 1 \cdot b_d, \text{ therefore}$$

$$h + 1 \cdot b_d < h + 1 \cdot b_s + 1 \cdot b_d \quad \text{and} \quad RT_{DDD} < \frac{RT_{DSS} + RT_{SDS} + RT_{SSD}}{3}$$

if the order of dimensional comparison is random. This prediction is confirmed by Bamber (1969, p. 171, Figure 1).

For the purposes of the present study, the following new predictions were generated from the serial self terminating model.

Prediction 5: If L increases and D remains fixed, reaction time for that particular value of D will increase.

$$\begin{aligned} \text{Proof: } RT_{\text{DIFFERENT}} &= h + 1 \cdot \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right] \\ &= h + 1 \cdot b_d + \frac{1 \cdot L \cdot b_s}{D + 1} + \frac{1 \cdot D \cdot b_s}{D + 1} \end{aligned}$$

Since D is fixed, $h + 1 \cdot b_d - \frac{1 \cdot D \cdot b_s}{D + 1}$ is a constant.

However, since $1 \cdot L \cdot b_s / D + 1$ clearly increases linearly with L, $RT_{\text{DIFFERENT}}$ increases with L $D + 1$ (this prediction also follows from Equation 1 and is confirmed by Bamber (1969, p. 171, Figure 1) and Hawkins (1969, p. 56, Figure 1)).

Prediction 6: If L remains fixed and D varies from $D = 1$ to $D = L$, then

$RT_{\text{DIFFERENT}}$ decreases as D increases.

$$\begin{aligned} \text{Proof: } RT_{\text{DIFFERENT}} &= h + 1 \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right] \\ &= h + 1 b_d + \frac{(L - D)}{(D + 1)} 1 b_s \end{aligned}$$

Since $D = 1, 2, \dots, L$, $L - D \geq 0$, i.e. positive.

As D increases $L - D$ becomes smaller, $\frac{1}{D + 1}$ becomes smaller and $(L - D) \left(\frac{1}{(D + 1)} \right)$ becomes smaller. Thus $h + 1 b_d + \left(\frac{L - D}{D + 1} \right) 1 b_s$ also becomes smaller (Bamber, 1969, p. 171, Figure 1; Hawkins, 1969, p. 56, Figure 1).

i) Random vs. Fixed Order

If the times required to process all the dimensions used in a particular experiment are approximately equal, subjects appear to be comparing these dimensions in a random order. Equation 2 and predictions 1 to 5 are based on a random order of comparison.

However, if processing time for a particular dimension is very much faster than for the others (e.g. Hawkins, 1969, p. 58, where the difference is > 100 ms), subjects appear to process dimensions in a fixed order; processing the fastest dimension first. In Hawkins (1969), processing time when the fastest dimension (colour) was present with any other difference, for example a colour and form difference vs. a colour and size difference, was almost identical to processing time for stimuli differing only in colour. This appears to indicate that subjects are processing colour first, and therefore that the order of processing dimensions is fixed.

Whether the order of processing dimensions is fixed can be determined

most easily by examining reaction times when $L = D$. In Prediction 1 (random order), RT was proven to increase with L ($L = D$). However, if a fixed order of comparison applies, the following prediction can be generated. Prediction 7: If reaction time for a single stimulus difference differs greatly from reaction time for other possible differences

$RT_{\text{DIFFERENT}}$ when $L = D$ will decrease as L increases.

Proof: Assume three possible differences exist, colour (b_{d1}), form (b_{d2}) and size (b_{d3}) such that reaction time of $b_{d3} > b_{d2} > b_{d1}$, see Hawkins (1969, p. 58), where the difference is > 100 ms. A fixed order of dimensional comparison is assumed.

When $L = 1$ and $D = 1$

$$RT_{\text{COLOUR}} = h + 1 b_{d1}$$

$$RT_{\text{FORM}} = h + 1 b_{d2}$$

$$RT_{\text{SIZE}} = h + 1 b_{d3}$$

$$RT_{\text{DIFFERENT (AVERAGE)}} = h + 1 \left(\frac{b_{d1} + b_{d2} + b_{d3}}{3} \right) \quad (\text{A})$$

When $L = 2$ and $D = 1$

$$RT_{\text{COLOUR} + \text{FORM}} = h + 1 b_{d1}$$

$$RT_{\text{FORM} + \text{SIZE}} = h - 1 \left(\frac{b_{d2} + b_{d3}}{2} \right)$$

$$RT_{\text{COLOUR} + \text{SIZE}} = h - 1 b_{d1}$$

$$RT_{\text{DIFFERENT (AVERAGE)}} = h + 1 \left(\frac{4 b_{d1} + b_{d2} + b_{d3}}{3} \right) \quad (\text{B})$$

To show $A > B$ it is sufficient to prove

$$\frac{b_{d1} + b_{d2} + b_{d3}}{3} > \frac{4 b_{d1} + b_{d2} + b_{d3}}{6}$$

$$6 b_{d1} + 6 b_{d2} + 6 b_{d3} > 12 b_{d1} + 3 b_{d2} + 3 b_{d3}$$

$$3 b_{d2} + 3 b_{d3} > 6 b_{d1}$$

$$\text{but } b_{d1} < b_{d2} \text{ and } b_{d1} < b_{d3}$$

$$\therefore b_{d1} + b_{d1} < b_{d2} + b_{d3} \text{ and}$$

$$2 b_{d1} < b_{d2} + b_{d3} \therefore$$

$$6 b_{d1} < 3 b_{d2} + 3 b_{d3}$$

When $L = 3$ and $D = 3$

$$RT_{\text{DIFFERENT}} (AV) = h + 1 b_{d1} \quad (C)$$

$$\text{Since } d_1 = \frac{6 b_{d2}}{6} < \frac{4 b_{d1} + b_{d2} + b_{d3}}{6}$$

$$C < B < A$$

This prediction was confirmed by Hawkins (1969). According to Bamber (1969) reaction time for same decisions can be symbolized

$$RT_{\text{same}} = L b_s + h \quad (3)$$

if a serial self terminating model is utilized. From the formula, it is possible to predict a linear increase for same reaction time as L increases. However, the reaction time for a single same decision (b_s) also increases as the number of possible differences (L) increases (Hyman, 1952). These two linear increases are equivalent to a quadratic increase. There-

fore, whenever subjects compare stimuli according to a serial self terminating model, reaction times for S decisions will show a quadratic increase as L increases. Thus Equation 1 above becomes

$$RT_{same} = Q(L)b_s + h \quad (4)$$

where $Q(L)$ is a quadratic in L to be determined experimentally.

$Q(L) = 1$ if $L = 1$. Thus, we have

Prediction 8: If we do not assume linear increase in b_s with L, we obtain Hawkin's (1969) result that RT increases linearly with L. The proof is given below.

Proof: For $L = 1$, $RTs = h^1 + s$

For $L = 3$, $RT_{sss} = h + 3s$

Since $s < 3s$ $\therefore h + s < h + 3s$

$\therefore RTs < RT_{sss}$

This result can also be proven for the quadratic case.

ii) Single Dimensional Comparison Times

Previous experimenters in the "same-different" paradigm, for example Bamber (1969) assumed isochronality. Under this assumption, reaction time for a single dimensional comparison resulting in a same judgment (b_s) equals reaction time for a single dimensional comparison resulting in a different

¹The length of h differs between the dominant and non-dominant hand but h is always constant for a particular subject using the same hand.

judgment (b_d). If isochronality is assumed, the serial self terminating model requires S reaction times to be longer than D¹ reaction times. However empirical results of many "same-different" experiments suggest that processing time for a single dimensional comparison is less for b_s than b_d , $b_s < b_d$ (Bamber, 1969, 1972; Grill, 1971; Hawkins, 1969). For example, values of b_s and b_d from Bamber's (1969) empirical results can be calculated as follows:

When $L = 1$ and $D = 1$

$$RT_{\text{SAME}} = h + b_s$$

$$RT_{\text{DIFFERENT}} = h + 1 \left[\frac{(L - D)}{(D + 1)} b_s + b_d \right]$$

$$= h + 1 \left[\frac{(1 - 1)}{(1 + 1)} b_s + b_d \right]$$

$$= h + 1 b_d.$$

Since $L = 1$, $RT_{\text{DIFFERENT}}$ reduces to $h + b_d$.

$$RT_{\text{DIFFERENT}} - RT_{\text{SAME}} = h + b_d - h - b_s$$

$$= b_d - b_s.$$

Therefore Bamber's isochronality assumption $b_d = b_s$ requires that $RT_{\text{DIFFERENT}} = RT_{\text{SAME}}$ when $L = D = 1$. From Bamber's data (1969, Tables 2 and 3, p. 172) we have $RT_{\text{DIFFERENT}} = 384.3$ and $RT_{\text{SAME}} = 337.9$, hence $b_d = b_s + 46.4$ msec., contrary to Bamber's isochronality assumption. When b_s is reliably less than b_d , a number of important consequences follow readily.

Prediction 9: If $b_s < b_d$, $RT_{\text{SAME}} < RT_{\text{DIFFERENT}}$ for low values of L and $RT_{\text{SAME}} > RT_{\text{DIFFERENT}}$ for high values of L . The relative speed of b_s and b_d

will determine the value of L required to obtain $RT_{\text{SAME}} > RT_{\text{DIFFERENT}}$.

Proof: $RT_{\text{DIFFERENT}} < RT_{\text{SAME}}$ if

$$h + \frac{(L + D)}{(D + 1)} b_s + b_d < h + L b_s$$

$$(L - D)b_s + (D + 1)b_d < b_s (D + 1)L$$

$$L b_s - D b_s + D b_d + b_d < L b_s D + L b_s$$

$$D b_d + b_d < L b_s D + D b_s + L b_s - L b_s$$

$$b_d (D + 1) < D b_s (L + 1) \quad (6)$$

Whenever this inequality is true, D reaction times will be faster than S reaction times.

The main points of Prediction 9 are evident from the following examples.

Example 1: When b_s is considerably faster than b_d , then with relatively small values of L the relationship between $RT_{\text{DIFFERENT}}$ and RT_{SAME} changes. In particular, suppose $2 b_s = b_d$, then substituting into Equation 6 we have

$$2 b_s (D + 1) < D b_s (L + 1).$$

$$\frac{2}{D + 1} < D (L + 1) \quad (7)$$

If this inequality is true, then D judgments are faster. When $L = 2$ and $D = 1$, Equation 7 becomes

$$2 (1 + 1) < 1 (2 + 1)$$

$$4 < 3$$

Therefore, the inequality (6) is not true and

$$RT_{\text{SAME}} < RT_{\text{DIFFERENT}}$$

When $L = 5$ and $D = 1$ Equation 6 becomes

$$2(1 + 1) < 1(5 + 1) \\ 4 < 6$$

Therefore, the inequality is true and $RT_{\text{SAME}} > RT_{\text{DIFFERENT}}$. In fact, for $L = 5$, $RT_{\text{SAME}} > RT_{\text{DIFFERENT}}$ for all D the difference in RT's increasing as D increases.

The next example illustrates the trade-off between the value of L required for the change in relation of the RT's and the relative values of b_s and b_d . If we assume a smaller difference between b_s and b_d than in Example 1, $RT_{\text{DIFFERENT}}$ will become faster than RT_{SAME} when L is smaller than in the previous example.

Example 2: Assume $1.25 b_s = b_d$. Then

$$1.25 b_s (D + 1) < D (L + 1) \quad (8)$$

If this inequality is true, then D reaction times will be faster than S reaction times.

When $L = 2$ $D = 1$ Equation 8 becomes

$$1.25(1 + 1) < 1(2 + 1) \\ 2.5 < 3$$

Therefore, the inequality is true and $RT_{\text{DIFFERENT}} < RT_{\text{SAME}}$.

Finally, if we assume a larger difference between b_s and b_d ,

$RT_{\text{SAME}} < RT_{\text{DIFFERENT}}$ until L assumes a larger value than in Example 1.

Example 3: Assume $4 b_s = b_d$. Then

$$4 b_s (D + 1) < D (L + 1) \quad (9)$$

If this inequality is true, then D reaction times will be faster than S reaction times.

When $L = 5$ and $D = 1$, Equation 9 becomes

$$4 (1 + 1) < 1 (5 + 1)$$

$$8 < 6$$

Therefore, the inequality is not true and $RT_{\text{SAME}} < RT_{\text{DIFFERENT}}^1$

B. Predictions from the Parallel Self Terminating Model

Since no predictive formulae are available for the parallel models, new formulae were developed. Predictions were then made from these formulae. According to Egeth (1966, p. 246), parallel models can be constant or distributed. A constant model is defined as a model in which "the time required to make a comparison along a single dimension is constant over all trials". A parallel distributed model is defined by Egeth as a model in which the time required for a dimensional comparison "fluctuates somewhat from trial-to-trial as would be the case if comparison times were distributed like a random variable".

For $i = 1, 2, \dots, L$, let b_i be the processing time for the i th dimension when the decision is same. For the various dimensions, e.g. colour, form, size, b_i 's are assumed to differ. If we assume the constant parallel

¹On page 86 of this report, figures for b_s and b_d from the present study are used to show that "fast" S reaction times can be predicted from Bamber's (1969) formula for serial self terminating models when $b_s < b_d$ and L is low.

TABLE 1'

A Summary of Predictions from the Modified SerialSelf Terminating Model

1. When $L = D$, reaction time increases as L increases.

$$2. \frac{RT_{DSS} + RT_{SDS} + RT_{SSD}}{3} > RT_{DDD}.$$

$$3. RT_D < RT_{DDD}.$$

$$4. RT_{DSS} > RT_{DDD}.$$

5. If L increases and D is fixed, RT for that particular value of D will increase.

6. If L remains fixed and D varies from $D = 1$ to $D = L$, then $RT_{DIFFERENT}$ increases as D increases.

7. If reaction time for a single dimensional comparison differs greatly from reaction times for other dimensional comparisons, $RT_{DIFFERENT}$ for $L = D$ will decrease as L increases.

8. $RT_S < RT_{SSS}$. As L increases, RT_{SAME} increases quadratically.

9. If $b_s \neq b_d$, then $RT_{SAME} < RT_{DIFFERENT}$ for low values of L and $RT_{SAME} > RT_{DIFFERENT}$ for high values of L . The relative speed of b_s and b_d will determine the value of L required to obtain $RT_{SAME} > RT_{DIFFERENT}$.

model, then

$$RT_{\text{SAME}} = h + \max (bi)^1 \quad (9)$$

If, however, we assume, as earlier, that reaction time for bi 's increases as L increases, then

$$RT_{\text{SAME}} = h + l_L (\max (bi)) \quad (10)$$

where l_L is some linear component such that $l_L \geq 1$, and l increases with L . Equation (10) applies to the distributed model (Hawkins, 1969). From Equation (10) it is possible to generate the following prediction.

Prediction 10: $RT_{\text{SSS}} > RT_z$.²

Proof: $RT_z = h + b_z$

$$\begin{aligned} RT_{\text{SSS}} &= h + l (\max (bi)) \\ &= h + l b_z \end{aligned}$$

Since $l \geq 1$, $l b_z > b_z$

$$\therefore h + l b_z \geq h + b_z$$

$$\therefore RT_{\text{SSS}} \geq RT_z$$

For $i = 1, 2, \dots, L$ let

di be the processing time for the i th dimension when the decision is different. When $L = D$

$$RT_{\text{DIFFERENT}} = h + \min (di),^3 \quad (11)$$

for the parallel constant model.

¹max = maximum.

² RT_z is reaction time for the slowest dimension when $L = 1$, RT_{SSS} is reaction time to judge same on three dimensions when $L = 3$.

³min = minimum.

For the parallel distributed model,

$$RT_{\text{DIFFERENT}} = h + \frac{1}{L} (\min (d_i)) \quad (12)$$

where $\frac{1}{L}$ is some linear component such that $\frac{1}{L} \geq 1$ and $\frac{1}{L}$ increases with L .

When L is fixed and $D = 1$

$$RT_{\text{DIFFERENT}} = h + \frac{\sum_i d_i}{L} \quad (13) \quad (\text{constant})$$

$$RT_{\text{DIFFERENT}} = h + \frac{1}{L} \frac{\sum_i d_i}{L} \quad (14) \quad (\text{distributed})$$

When L is fixed and $D = 2$

$$RT_{\text{DIFFERENT}} = h + \frac{\sum_{i < j} \min (d_i, d_j)}{L} \quad (\text{constant})$$

$$RT_{\text{DIFFERENT}} = h + \frac{1}{L} \frac{\sum_{i < j} \min (d_i, d_j)}{L} \quad (\text{distributed})$$

When L is fixed and $D = 3$

$$RT_{\text{DIFF}} = h + \frac{\sum_{i < j < k} \min (d_i, d_j, d_k)}{L} \quad (\text{constant})$$

$$RT_{\text{DIFF}} = h + \frac{1}{L} \frac{\sum_{i < j < k} \min (d_i, d_j, d_k)}{L} \quad (\text{distributed})$$

For any D the formula becomes

$$RT_{\text{DIFF}} = h + \frac{\sum_{\substack{i_1, i_2, \dots, i_D \\ i_1 < i_2 < i_3 \dots < i_D}} \min (d_{i_1}, d_{i_2}, \dots, d_{i_D})}{L} \quad (\text{constant})$$

$$RT_{\text{DIFF}} = h + \frac{1}{L} \frac{\sum_{\substack{i_1, i_2, \dots, i_D \\ i_1 < i_2 < i_3 \dots < i_D}} \min (d_{i_1}, d_{i_2}, \dots, d_{i_D})}{L} \quad (\text{distributed})$$

In Hawkins (1969), a table of predictions for the parallel model was

given. These predictions were made without proof. Mathematical proof that these predictions are a necessary consequence of the model, will now be given. Two of the present proven predictions do not agree with Hawkins' earlier predictions. To facilitate comparison, Hawkins' notation will be utilized. Hawkins made predictions only for the three-dimensional case ($L = 3$) with $D = 1$ and $D = 3$. Let RT_x be the reaction time to judge that a difference exists on dimension x when $L = 1$ and $D = 1$. RT_y and RT_z are defined similarly. $RT_x(yz)$ denotes the reaction time to judge that x is different and y and z are the same when $L = 3$ and $D = 1$. $RT_y(xz)$ and $RT_z(xy)$ are defined similarly. RT_{xyz} denotes the reaction time to judge that x , y , and z are different ($L = 3$ & $D = 3$).

i) Predictions for Parallel Self Terminating Distributed Model

$$\text{Prediction 11: } \frac{RT_{x(yz)} + RT_{y(xz)} + RT_{z(xy)}}{3} > RT_{xyz}$$

Proof: Let $d1 = RT$ to complete the first dimensional comparison
on dimension x

$d2 = RT$ to complete the second dimensional comparison
on dimension y

$d3 = RT$ to complete the third dimensional comparison
on dimension z

Let $d3 > d2 > d1$

$$RT_{DDD} = h + 1_s (\min (di)) = h + 1_3 d_1$$

$$\frac{RT_{DSS} + RT_{SDS} + RT_{SSD}}{3} = h + 1_3 \frac{\sum di}{3}$$

$$= h + \frac{l_3 (d_1 + d_2 + d_3)}{3}$$

However $d_1 < d_2 < d_3 \therefore d_1 + d_2 + d_3 > d_1 + d_1 + d_1$

$$\therefore \frac{d_1 + d_2 + d_3}{3} > \frac{3d_1}{3}$$

$$d_1 + d_2 + d_3 > 3d_1$$

$$\therefore h + \frac{l_3 (d_1 + d_2 + d_3)}{3} > h + l_3 d_1$$

$$\therefore \frac{RT_{DSS} + RT_{SSD} + RT_{SDS}}{3} > RT_{DDD}$$

(Bamber, 1969, p. 171, Figure 1).

Prediction 12: $RT_x < RT_{xyz}$

Proof: Define d_1 , d_2 and d_3 as in Prediction 11. Let $d_1 < d_2 < d_3$

$$RT_x = h + l_1 d_1 \quad RT_{xyz} = h + l_3 d_1$$

$$l_1 > l_3 \therefore l_1 d_1 < l_3 d_1$$

$$\therefore h + l_1 d_1 < h + l_3 d_1$$

$$\therefore RT_x < RT_{xyz} \quad (\text{Bamber, 1969, Hawkins, 1969}).$$

RT_y and RT_z cannot be compared to RT_{xyz} .

$$\text{Proof: } RT_y = h + l_1 d_2 \quad RT_z = h + l_1 d_3$$

$$RT_{xyz} = h + l_3 (\min(d_i)) = h + l_3 d_1$$

$$\text{Now } d_1 < d_2 \quad \text{and} \quad d_1 < d_3$$

$$\text{but } l_3 > l_1 \quad \text{and} \quad l_3 > l_1$$

Therefore $l_3 d_1$ and $l_1 d_2$ cannot be compared and

$l_3 d_1$ and $l_1 d_3$ cannot be compared.

Prediction 13: $RT_{x(yz)} = RT_{xyz}$

Proof: $RT_{x(yz)} = h + l_3 d_1$

$$\begin{aligned} RT_{xyz} &= h + l_3 (\min(d_i)) \\ &= h + l_3 d_1 \end{aligned}$$

This prediction has not been confirmed in any "same-different" experiment to date.

ii) Predictions for Parallel Self Terminating Constant Model

Prediction 14: $RT_z = RT_{sss}$.

Proof: $RT_z = h + b_3$ where $b_1 < b_2 < b_3$.

$$RT_{sss} = h + (\max(b_i)) \text{ but } \max b_i = b_3$$

$$\therefore RT_{sss} = h + b_3 = RT_z$$

Prediction 15: $\frac{RT_{x(yz)} + RT_{y(xz)} + RT_{z(xy)}}{3} > RT_{xyz}$

$$\text{Proof: } \frac{RT_{x(yz)} + RT_{y(xz)} + RT_{z(xy)}}{3} = h + \frac{\sum d_i}{3}$$

$$= \frac{h + d_1 + d_2 + d_3}{3}$$

$$\begin{aligned} RT_{xyz} &= h + (\min(d_i)) \\ &= h + d_1 \end{aligned}$$

$$\text{Now } d_1 + d_1 + d_1 < d_1 + d_2 + d_3$$

$$\therefore \frac{d_1 + d_1 + d_1}{3} < \frac{d_1 + d_2 + d_3}{3}$$

$$\therefore h + \frac{3 d_1}{3} < h + \frac{d_1 + d_2 + d_3}{3}$$

$$RT_{xyz} < \frac{RT_{DSS} + RT_{SDS} + RT_{SSD}}{3}$$

Prediction 16: $RT_x = RT_{xyz}$ where x is the fastest processed dimension.

Proof: $RT_x = h + d_1$

$$\begin{aligned} RT_{xyz} &= h + (\min (d_i)) \\ &= h + d_1 \end{aligned}$$

Prediction 17: $RT_{x(yz)} = RT_{xyz}$

Proof: $RT_{x(yz)} = h + d_1$

$$\begin{aligned} RT_{xyz} &= h + (\min d_i) \\ &= h + d_1 \end{aligned}$$

C. Distinguishing Serial from Parallel Models

To distinguish parallel from serial models, RT_{SAME} should be examined. As L increases, RT_{SAME} increases linearly for parallel models but quadratically for serial models.

If subjects appear to be processing stimuli according to a serial model, relative reaction times for S and D judgments should then be examined to determine whether the predictions listed in Table 1, p. 43, are confirmed. Failure to confirm any prediction would suggest the model

TABLE 2

A Summary of Predictions from the Parallel SelfTerminating ModelA. Distributed Model

$$10. RT_{sss} > RT_z$$

$$11. \frac{RT_{x(yz)} + RT_{z(xz)} + RT_{z(xy)}}{3} > RT_{xyz}$$

$$12. RT_x < RT_{xyz}$$

RT_y and RT_z cannot be compared to RT_{xyz} .

$$13. RT_{x(yz)} = RT_{xyz}$$

B. Constant Model

$$14. RT_z = RT_{sss}$$

$$15. \frac{RT_{x(yz)} + RT_{y(xz)} + RT_{z(xy)}}{3} > RT_{xyz}$$

$$16. RT_x = RT_{xyz}$$

$$17. RT_{x(yz)} = RT_{xyz}$$

is not applicable whereas confirmation of all predictions would suggest that subjects are comparing stimuli according to the serial self terminating model.

Similarly, whenever subjects appear to be processing stimuli according to a parallel model, the predictions of Table 2, page 50, should be tested. With parallel models, either predictions 10, 11, 12 and 13 for the parallel self terminating distributed model or predictions 14, 15, 16 and 17 for the parallel self terminating constant should be confirmed before use of a parallel model would be indicated.

CHAPTER III

Experimental Investigation of "Same-Different"

Judgments and Methodological Issues

In just over a decade an enormous and impressive literature detailing the variety of factors influencing "same-different" judgments has arisen. In this section, we briefly review this literature pointing out the methodological variables of importance to the present experiments. In particular, we present detailed statements of the relevance of each of these factors in the form of explicit hypotheses in the context of the experiments to be reported.

(A) Characteristics of the Stimuli. When required to decide whether two stimuli are the same or different, adults compare the stimulus objects according to a fast parallel process if stimulus differences are easily discriminable (Nickerson 1967, 1969). Such parallel processing also requires codable stimuli (Bindra, Donderi and Nishisato, 1968). According to Bamber's (1969) Two-Process Model, S reaction times are faster than D reaction times when parallel processing is utilized for S judgments. Therefore, Nickerson (1967, 1969) would predict that adults would have faster S reaction times than D reaction times when stimulus differences were easily discriminable and the stimuli themselves were codable. According to Egeth (1966), adult subjects would have D reaction times which are faster than S reaction times, if serial self-terminating processing is employed. Thus Nickerson (1967, 1969) would predict that adult subjects would have D reaction times which were faster than S reaction times

if the stimulus differences were difficult to detect.

Accordingly, the following hypothesis could be constructed. (1) If differences between stimuli are easy to detect, adult S reaction times will be shorter than adult D reaction times.

(B) Developmental Status of the Subject. If a well defined relation in same and different reaction times were established for adults, experiments would then be necessary to determine at what stage of development this relation occurs in children. Studies of stimulus separability indicate that young children are able to process dimensions individually in some cases but not in others (Kemler and Smith, 1979). If children process "same-different" stimuli differently than adults, age should interact with other variables in a "same-different" investigation involving adult and young child subject groups.

The serial self terminating model requires subjects to compare stimuli along one dimension at a time. If stimuli are integral for children, then serial self terminating comparison will be impossible for them. If adults compare stimuli according to a serial self terminating model and children cannot utilize this form of comparison then only adult results should confirm all predictions from the serial self terminating model.

Accordingly, the following hypotheses are constructed: (2) If same and different reaction times of young children, older children, and adults are analyzed by means of analysis of variance, there will be a main effect of age and an interaction between age and at least one other experimental variable. (3) If same and different reaction times for adults

confirm predictions from the serial self terminating model, then same and different reaction times for young children will not confirm all predictions from the serial self terminating model.

A young child still in the process of acquiring the concepts of sameness and difference might possibly detect and process stimulus differences less readily than an adult. Thus the stimulus differences "readily discriminable" for the adult might well be "difficult to distinguish" for the child. Adults, therefore, should show faster S reaction times than D reaction times to a set of stimuli because of their ability to make more efficient comparisons or because they use parallel processing. On the other hand, young children should exhibit faster D reaction times because they use serial self terminating processing since they find the differences between the stimuli difficult to detect.

In Jansen's (1974) study, however, stimuli were allowed to differ along two dimensions, colour and form. S reaction times were faster than D reaction times for stimuli differing on a single dimension (D' reaction times). Therefore, these results suggest that the developmental status of the subject does not appear to determine the appropriate model.

Possibly both adults and children find differences between stimuli easy to detect when only two dimensions, form and colour, are involved. By increasing the number of dimensions along which differences could occur, difficulty of detection might increase. For young children who are still in the process of learning to detect sameness and difference, task difficulty might possibly increase more quickly than for adults. Thus children would fail to demonstrate fast S reaction times with fewer dimensions of difference than adults.

Accordingly, the following hypotheses could be constructed:

(4) If stimuli are allowed to differ along at most, two dimensions, S reaction times will be shorter than D' reaction times for adults, older children and younger children.

(5) If the maximum number of possible differences increases from two to five in one unit steps, faster S reaction times than ~~D~~ reaction times will be eliminated first in younger children then in older children and finally in adults.

(C) Practice Effects. According to Grill (1971) and Corcoran (1967), adult subjects shift from serial to parallel processing after sufficient practice. If these findings are replicated in the present experiment, then Hypothesis (6) should hold.

(6) An analysis of variance of S and D reaction times will reveal a main effect of "days" and an interaction involving days and at least one other experimental variable.

(D) Role of Conflict. Jansen's (1974) subjects made fewer errors on stimuli in which both of the possible differences, form and colour, were present than on stimuli requiring an S judgment. This could be interpreted as evidence that two differences were easier to detect than two identities. From this, one would assume that fewer errors would have been made on slides in which the stimulus objects were different on one dimension and the same on the other. Jansen's (1974) subjects, however, made more errors on such stimuli than either S stimuli or D stimuli with difference on both dimensions. This was interpreted as a possible indication of an additional factor operating in the situation. This factor, conflict, could

cause the subject to hesitate and take a second look at stimuli in which the comparison along one dimension resulted in a judgment which conflicted with the judgment resulting from the comparison along the other dimension. This conflict could serve to increase errors and to increase reaction time. If one were to hypothesize greater conflict in younger age groups, faster S reaction times could result more from conflict than from parallel processing.

If stimuli were allowed to differ along four dimensions, the conflict hypothesis would predict maximum D reaction times when differences occurred on two of the four dimensions. However, examination of available results fails to produce support for the conflict hypothesis. Bamber (1969) found maximum D reaction times occurred when only one of the four possible differences was present. Maximum D reaction times also occurred when stimuli differed on one of four dimensions in experiments by Egeth (1966), Silverman and Goldberg (1975), Donderi and Case (1970), Derks (1971) and Eichelman (1970).

Accordingly, on the basis of these studies it would be possible to construct the following hypothesis:

(7) When five differences between stimuli are possible, reaction times will be longest for stimuli with only one difference present, followed in order by stimuli with two differences present, three differences present, four differences present and five differences present.

Summary of Hypotheses

1. If differences between stimuli are easy to detect, adult S reaction times will be shorter than adult D reaction times.
2. If same and different reaction times of young children, older children, and adults are analyzed by means of analysis of variance, there will be a main effect of age and an interaction between age and at least one other experimental variable.
3. If same and different reaction times for adults confirm all predictions from the serial self terminating model, then same and different reaction times for young children will not confirm all predictions from the serial self terminating model.
4. If stimuli are allowed to differ on a maximum of two dimensions, D reaction time will be shorter than D' reaction time for adults, older children and young children.
5. If the maximum number of possible differences increases from two to five in one unit steps, faster S reaction times will be eliminated first in younger children, then in older children and finally in adults.
6. An analysis of variance of S and D reaction times will reveal a main effect of "days" and also an interaction between "days" and at least one of the experimental variables.
7. When five differences between stimuli are possible, reaction times will be longest for stimuli with only one difference present followed in order by stimuli with two differences present, three differences present, four differences present and five differences present.

Methodological Issues

In designing experiments to test the foregoing hypotheses, not only theoretical but methodological issues were important. As in the previous ten years of experimentation using the "same-different" paradigm, control of possible bias factors was essential.

(i) Bias arising from Hand Dominance

Two response buttons, side by side, have been used to indicate S or D judgments in the "same-different" paradigm. Subjects push one button to indicate an S decision, while the other button is used to record a D judgment. Naturally, if the dominant hand is always used for the S button, S decisions will be recorded more quickly. Similarly, if the dominant hand were used to indicate D decisions, these would be faster than S judgments.

To control for this obvious bias, Bamber (1969, 1972), Nickerson (1967, 1969) and Tversky (1969, 1973) required half their subjects to indicate S decisions by pushing a button with a finger of the dominant hand while the other half of the subjects used the non dominant hand to indicate D judgments. This method of controlling hand dominance, used most frequently in the "same-different" paradigm, has the advantage of simplicity for the subject.

Alternatively, other researchers such as Bindra, Williams and Wise (1965) and Bindra, Donderi and Nishisato (1968) have used a "one-handed" method of hand dominance control. In these experiments, subjects are all required to press the button with a finger of the dominant hand on every trial. Between trials, each subject rests the index finger of the dominant

hand on a key located midway between two buttons. Half of the subjects indicate an S judgment by pressing the button to the right of the key while the remaining subjects use this button to record a D decision. Similarly, the first half of the subjects use the button to the left of the key to render a D judgment while the remaining subjects use it to record an S decision. Little variation in the distance between central key and buttons is found. Coltheart and Curthoys (1968) used 1 in., Bindra, Dondéri and Nishisato (1968) 1.5 in., and Entus and Bindra (1970) 2 in. As the same hand is used by each subject to record both S and D decisions, less variability in reaction time could be attributed to factors other than speed of reaching an S or D judgment. This method, however, has not been tested with 5-6 year old children. In contrast, unpublished studies by Petrusic (personal communication) indicate the suitability of the two handed method for use with 5-6 year old children.

A lever was used by White (1960) in a variation of the one hand procedure. In this choice reaction time experiment, subjects were required to push the lever up if one stimulus was shown and down if another appeared. After each judgment was given, the lever was returned to the middle position. The next trial could not begin unless the lever was in the correct position. Sekuler and Abrams (1968) utilized this method of recording decisions in their "same-differen" study. In contrast to White's (1965) study, Sekuler's and Abrams' switch was pushed from right to left. Half of the subjects indicated an S decision by moving the switch to the right while this movement indicated a D decision for the remaining subjects. This corrected for the faster movement of the switch to the right. The switch was spring loaded to make finding the middle position easier.

One button was used by Tversky's (1973) child subjects. For S judgments, the child said "yes" and pushed the button, while D judgments were given by a "no" and push to the same button.

If a "yes" response required a shorter latency than a "no" response, reaction times obtained could be seriously affected by bias. For this reason, Tversky's (1973) method of correcting for hand dominance was judged unsuitable for use in a previous study (Jansen 1974). Results obtained in this study confirmed that the two button method could be mastered by 5 and 6 year old children. The two handed method was also used by many of the researchers whose theories and experiments are of prime importance to the present study, Bamber (1969, 1972), Bamber et al (1975), Egeth (1966) and Nickerson (1967, 1969). For these reasons, the two handed method was chosen for use in the present study.

(ii) Bias from the Sequential Effects of Response Repetition

Circumstances under which responses are faster when stimuli are the same as those used in the preceding trial are described by Cantor (1969). Where only two possible alternatives exist in a choice reaction time task requiring the naming of alternatives, response times are significantly faster for repeated stimuli. Shorter reaction times for repeated stimuli as compared to alternating or randomly alternating stimuli were found by Bertelson (1961). In this task, adult subjects were required to push the left hand button if one light flashed and the right hand button if the other light flashed. Bertelson (1963) also found shorter reaction times for repeated stimuli when four alternatives were used. Bertelson and Rankin (1965) however, found that the difference in reaction time in favour of repeated stimuli, decreased as the time interval between stimulus

presentation increased. Repeated stimuli were also found to have significantly shorter reaction times by Remington (1969), who used a choice reaction time task with four possible alternatives. With a six choice reaction time task in which the probability of occurrence of each stimulus was varied at each trial, Falmagne (1965) found shorter reaction times for repeated stimuli and this result was verified by Krinchik (1969) with two to eight stimulus alternatives.

In choice reaction time studies, the apparatus used to record judgment times is similar to that employed in the "same-different" paradigm. In both paradigms, stimuli are displayed on a screen in front of the subject. The individual is required to push one of two buttons, basing his decision upon the stimulus display. Sequential effects observed in choice reaction time studies, therefore, are also present in "same-different" experiments.

Although shorter reaction times for repeated stimuli have not occurred in all¹ choice reaction time experiments, the possibility is sufficiently strong to warrant counterbalancing of repeated and changed stimuli in a "same-different" study.

In the "same-different" paradigm, moreover, a significantly shorter reaction time was found for repeated stimuli. In these experiments (Krueger 1973, Eichelman 1970 a and b) letter stimuli were used. Relative reaction times for S and D judgments were affected as S reaction times

¹No effect of repeated stimuli was found by Cantor and Cantor (1964), Bogartz (1965, 1967) and Bogartz and Witte (1966).

were shortened more than D reaction times when the response on a particular trial was identical to that of the previous trial. This demonstration of the sequential effects of response repetition in the "same-different" paradigm itself makes control of this factor even more essential.

(iii) Bias arising from Sequential Effects of Stimulus Repetition

The number of possible stimulus pairs resulting in an S decision is smaller than the number of possible stimulus pairs resulting in a D decision for any given set of stimuli. The effect of stimulus repetition upon "same - different" reaction time was investigated by Nickerson (1969), Eichelman (1970 a and b) and Krueger (1973), all of whom utilized letter stimuli. Significantly shorter reaction times were found when the stimuli were identical to the previous trial, S responses being more strongly affected than D decisions. Two successive identical S pairs, moreover, are more likely to occur than two successive identical D pairs since the number of possible S pairs is smaller than the number of possible D pairs for any given set of stimuli.

(iv) Bias arising from Proportion of Same and Different Judgments

The proportion of S trials in a particular study was found to affect relative reaction times in "same-different" studies (Coltheart and Curthoys, 1968; Bindra, Williams and Wise, 1965). Bindra, Williams and Wise, using stimuli which differed only in pitch, found S reaction times decreased significantly when the proportion of trials requiring an S decision increased from 10% to 90%. Similarly, D decision times decreased significantly when the proportion of trials requiring a D judgment

increased from 10% to 90%.

Downing (1970) also investigated response probabilities in the "same-different" paradigm. When the number of S responses equalled the number of D responses, average S reaction time was shorter than when three D responses were required for every S response. When the number of S responses was equal to the number of D responses, S reaction time was shorter than D reaction time. When three D responses were required for every S response, D reaction times were faster than S reaction time. Downing suggested that processing criteria for S decisions might change with the proportion of S responses. If a high proportion of responses required S decision, subjects may spend less time looking for a difference. Because an S decision has a high probability of being correct, subjects might report an S decision before processing was complete on all dimensions. In contrast, whenever a low proportion of S responses was required, subjects would wait until processing was complete on all dimensions.

The relative reaction time of S and of D decisions was also found to depend upon the instructional emphasis placed upon speed as compared to accuracy (Bindra, Williams and Wise, 1965). This factor, however, is relevant only to stimuli differing along a single dimension. The present study, which investigates relative reaction times for S and D decisions differing along two to five dimensions, is not affected by the variable.

(v) Repetition of Specific Stimulus Pairs

If the number of S judgments equals the number of D judgments, specific same pairs (e.g. two red circles) are more likely to appear than specific different pairs (e.g. a red circle and a blue circle). If

reaction time decreased with each exposure to a specific stimulus pair, faster S reaction times could be an artifact of more frequent repetition of specific S stimulus pairs. The importance of this bias has been discounted by Nickerson (1968, 1973), Krueger (1973) and Williams (1972) who demonstrated that the repetition of specific stimulus pairs made no significant contribution to the difference between S and D reaction times.

CHAPTER IV

Method

A. Subjects

Two hundred and forty subjects were used:

80 Kindergarten children with a mean age of 5 years, 7.5 months ($\pm$ 5.2 mon),
80 Grade 6 children with a mean age of 11 years, 8.6 months ($\pm$ 6.1 mon)
and 80 university students with a mean age of 21 years, 3.0 month
($\pm$ 14.5 mon). Each group was composed of an equal number of males and
females. Kindergarten and Grade 6 subjects were pupils of the Ottawa Roman
Catholic school board from the following schools: St. George, St. Elizabeth,
and Corpus Christi. These schools were chosen as their pupils represented
a cross section of socio-economic strata. Adults, undergraduate students
at the University of Ottawa, were drawn from a second year course in De-
velopmental Psychology and from a first year course in Introductory Cal-
culus. Subjects were of normal intelligence with normal or normal correct-
ed vision. Children of below normal intelligence were defined as those
whose difficulty with academic learning had led their teacher to suspect
they were "slow learners".

B. Design and Stimuli

Twenty subjects from each age group were randomly assigned to one
of four sub-groups labelled 2D, 3D, 4D and 5D. Random assignment was sub-
ject to the restriction that each sub-group consist of ten males and ten
females. Group 2D subjects viewed stimuli which were allowed to differ
only along the dimensions of form and/or colour. Group 3D subjects were

exposed to stimuli which were permitted to differ along the dimensions of form and/or colour and/or size. Group 4D subjects were presented with stimuli which were allowed to differ along the dimensions of form and/or colour and/or size and/or orientation of a centre black line. Group 5D subjects viewed stimuli which were allowed to differ along the dimensions of form and/or colour and/or size and/or orientation of a centre black line and/or margin solidarity.

Each subject viewed 288 slides in three separate experimental sessions held on different days. Ninety-six slides were presented during each of these experimental sessions. Each block of 96 slides was subdivided into two blocks of 48 slides each, 24 trials requiring an S judgment and 24 requiring a D decision.

Stimulus objects were either two dimensional squares or circles. Each object was either red or blue. Except for group 2D, each stimulus object could be either large (18 cm) or small (10 cm). With the exception of groups 2D and 3D, a centre black line on each stimulus object could be either horizontal or vertical. For group 5D, a black margin on each figure could be either solid or broken.

For group 2D stimuli, each set of 48 stimuli consisted of 24 stimuli with differences in both form and colour,¹ 12 in which stimuli differed on form alone, and 12 in which the stimuli differed on colour alone.

¹Admittedly, this particular selection of dimensions on which stimuli differed was confounded with the number of dimensions on which the pairs differed. This confounding is surely likely to be inconsequential since the assignment of form and colour to the pairs in the 2D set is natural and serves as a basis for a reasonable construction of stimulus pairs in the 3D, 4D and 5D stimulus sets.

For group 3D, each set of 48 D stimuli consisted of 16 stimuli with differences on form, colour, and size, 16 with differences on form, colour, or size and 16 with two differences drawn from the dimensions of form, colour and size. For group 4D, each set of 48 D stimuli consisted of 12 stimuli with differences on form, colour, size and centre line orientation, 12 stimuli with differences on form, colour, size or centre line orientation, 12 stimuli with two differences drawn from the dimensions of form, colour, size and centre line orientation and 12 stimuli with three differences drawn from the same possible difference dimensions. For the 5D group, each set of 48 D stimuli consisted of nine stimuli with differences along the dimensions of form, colour, size, centre line orientation and margin solidarity, nine with differences along only one of the above dimensions, ten with two differences drawn from the above dimensions and ten with three differences from the above dimensions while an equal number possessing four such differences also were shown. A complete listing of the total variety of slides used for the D stimuli is available from the author.

Identical pairs were constructed by varying all possible values on each of the dimensions on which the stimuli differed in the D pairs. For example, the set of 2D identical pairs was composed of two large red circles, two large red squares, two large blue circles and two large blue squares, all with a vertical centre black line and a solid border. A complete listing of the stimuli used for the 3D, 4D and 5D identical pairs is available from the author.

The number of S trials preceded by S trials was equal to the number of D trials preceded by D trials in each block of 48 trials. Moreover,

the number of S trials preceded by D trials was equal to the number of D trials preceded by S trials for each block of 48 trials. Thus for S decisions, the number of "repeated trials" in which the decision was identical to that given on the previous trial was equal to the number of "changed trials" in which the decision was not the same as that given on the previous trial.

Furthermore, for D judgments, the number of "changed trials" also equalled the number of "repeated trials" while the number of both "repeated" and "changed" trials for S decisions was identical to that for D judgments. If a D judgment followed a D judgment or an S decision followed an S decision, the actual stimulus pairs were not identical. For each group, 10 subjects pushed a S button with their dominant hand. The remaining 10 subjects of each group pushed a D button with their dominant hand.

C. Apparatus

A wooden partition, 1 m. square and painted white, was positioned on a table approximately 25 cm from the seated subject. This partition served to conceal the projector and timing devices from the subject's view. A rectangular opaque screen, 25.8 cm long and 19 cm wide, was inserted into the partition. For each group of subjects, the height of the table and screen was adjusted so that the centre of the screen was approximately at eye level. Each of the two response buttons was located 8 cm below the screen and exactly 2.58 cm (one inch) to one side of the centre of the screen. A 5.2 by 7.7 cm card on which either "S" or "D" was printed was placed below the appropriate button.

Behind the partition and hidden from the subject's view, a Kodak Carousel projector, model 650, was placed 1.55 m. from the partition for rear projection onto the screen. An adaptation to the remote control unit of this projector enabled the slides to be changed automatically by a repeat cycle timer, Lafayette model 5661 AP, which was connected to a triple pulse former, Lafayette model 58021.

On each trial, the subject's reaction time was measured by a digital clock counter, Lafayette model 54517 and automatically recorded by a printer, Lafayette model 56025 (see Appendix A for wiring diagram).

At the beginning of each trial, the slide was projected onto the screen, and initiated the counter to begin timing the subject's reaction time. When the subject pushed either button, the counter stopped and the time was printed to the nearest one thousandth of a second. The repeat cycle timer then advanced the projector to the next slide, with a three second delay.

D. Procedure

Each experimental session consisted of 10 practice trials followed by 96 test trials. The procedure for each test session is described below in detail.

Group K - Day 1. The experimenter brought each child into the experimental room in which the apparatus had been placed on a central table. The child was seated in a chair in front of the apparatus screen. The experimenter instructed the child as follows:

Let's look at my picture book first [Subject and experimenter seat themselves at the table] These pictures are on the machine now. Do you know what they are? What is this one?

[The experimenter points to the circle and waits for a reply. This is repeated for the square. If the child does not know the name of the symbol, the experimenter gives it to him. The experimenter then turns to the page showing symbol pairs.] Here is a red circle. Here is another red circle. Are they the same? The experimenter waits for a reply. Good. Here is a red circle. Here is a blue square. Are they different? [The experimenter waits for a reply.] Good. Here is a blue square. Here is a blue circle. Are they different? The experimenter waits for a reply. Good. One is a square and one is a circle. [The experimenter points to the appropriate object.] Here is a red circle and here is a blue circle. Are they different? [The experimenter waits for a reply.] Good. One is red and one is blue. [The experimenter points to the appropriate object. These instructions are then repeated with 5 more stimulus pairs.]¹

The experimenter then instructed the child as follows:

Now come work the machine. Here is a red circle and here is another red circle. [The experimenter points to each.] Are they the same? [The experimenter waits for a reply.] Good. When they are the same, push the same button. [The experimenter demonstrates.] This button has S under it. Now here is a blue circle and here is a red square. [The experimenter points to each.] Are they different? [The experimenter waits for a reply.] Good. When they are different, push the different button. [The experimenter demonstrates the action.] The different button has D under it. They are different. Now you do it. [A slide with two blue squares is shown. If the child does not push the same button, the experimenter says "Push same". This is repeated for 10 trials, the experimenter prompting when necessary.]² You work the machine nice and fast. You can go fast and not get any wrong. Here are some more for you to do. [The 96 test trials are then presented.]

¹If the subject responded correctly, the experimenter proceeded to the machine. If the subject did not respond correctly, the experimenter repeated the training procedure with the second set of pictures. If the subjects still did not respond, they were eliminated from the study. None were.

²If the subject did not respond correctly during the 10 practice trials, the instructions for the use of the machine were repeated. A second set of 10 practice slides was then presented. If the subjects still did not respond correctly, they were eliminated from the study. None were.

Group K - Day 2 and 3. The instruction with the book was omitted but the use of the machine reviewed.

Group 6 - Day 1. The experimenter brought each child individually into the experimental room seating him in front of the apparatus. The experimenter instructed the child using pictures as follows:

This is a machine to test how fast you can get the right answers. It shows pictures like this. [The experimenter shows a card on which the stimuli are displayed, points to each and names it. A flash card with two red circles was then displayed.] Are these the same? [The experimenter waits for an answer.] When they are the same, push button S. [The experimenter demonstrates. A card showing a red circle and a blue square is then presented.] Are these different? [The experimenter waits for a reply.] When they are different, push the D button. [The experimenter demonstrates. A card showing a blue square and a blue circle is then presented.] Are these different? [The experimenter waits for a reply.] Yes, one is a circle and the other is a square. Now push the right button. [This procedure is repeated with a red square and a blue square.] Now try the practice ones on the machine. Do them as fast as you can without making mistakes. [Ten practice trials are then run.]¹ You work fast and have few mistakes. Now here's the test [96 test trials are then run]

Group 6 - Day 2 and 3. The practice was the same as for Day 1 but with the following instructions:

Today we will run the machine with the pictures in a different order. First, let's practice. [Ten practice trials are then run.] Now we are ready to go. Be correct every time but be fast too. [96 test trials are then run]

Group A - Day 1. Each subject was brought into the room individually and seated in a chair in front of the apparatus. The experimenter

¹If the subject did not respond correctly during the 10 practice trials, instructions for use of the machine were repeated. A second set of practice slides was then presented. If the subjects still did not respond correctly, they were eliminated from the study. None were.

instructed the subject using pictures as follows:

This is a machine to test how fast you can make decisions - the right decision, of course! It shows pictures like this. [The experimenter shows a card on which the stimuli are displayed, points to each in turn and names it.] Each time we will show you two pictures. [Two red circles appear on the screen.] If the two pictures are exactly the same, push the S button. [The experimenter demonstrates. The picture changes to a red circle and a blue square.] If the two pictures are different, push the D button. [The experimenter demonstrates. The picture changes to a blue circle and a blue square.] Different shape is different. [The experimenter pushes the D button. A red square and a blue square appear.] Different colour is different. The experimenter demonstrates. Any difference at all, push D. If they are the same, push S. Now here are some for practice. Do them as fast as you can without making mistakes. [Ten practice trials are then given.]¹ Good! Now here's the real test. Remember to be fast and accurate.

Group A - Day 2 and 3. The procedure was the same as for group 6, Day 2 and 3.

¹ Adults not responding correctly on practice trials were treated in the same way as child subjects who did not respond correctly in practice.

CHAPTER V

Results

The findings are presented in three main sections. The first provides summaries of the main aspects of performance and, using analysis of variance (ANOVA), determines the statistical reliability of the effects of age, practice, stimulus format and importantly, number of dimensions, separately for S and D response times. The second examines S and D response times with respect to the various predictions from alternative models. The final section examines response times for specific stimulus combinations, providing further detailed tests of the alternative models. Throughout, the findings are presented separately and in detail for each age level providing the major focus of the analysis in each section.

A. Main Aspects of Task Performance

Since overall error rate was low, 3.5%, all analyses are based on mean correct response times. Table 3 summarizes the main features of task performance providing means and standard deviations of response times for S judgments and D judgments when stimuli differed on all dimensions (D^{ALL}), when stimuli differed on the one most salient feature (D^{SAL}) and when stimuli differed on but one dimension (D^1). These response times are presented as a function of number of possible differences, separately for each age group.

TABLE 3
Means and Standard Deviation of Reaction Time for S, D^{ALL}, D^I and D^{SAL} Judgments according to Age Group, Number of Possible Differences in the Stimuli, and Days

Number of Possible Differences	Age Group	Day 1			Day 2			Day 3						
		S	D	D ^I	SAL	S	D ^{ALL}	D ^I	SAL	S	D ^{ALL}	D ^I	SAL	D
2	K n = 20	Mean SD	1.481 .27	1.494 .26	1.829 .26	1.824 .28	1.350 .25	1.322 .25	1.509 .27	1.488 .25	1.309 .23	1.262 .23	1.423 .23	1.419 .25
	Grade 6 n = 20	Mean SD	.978 .14	.685 .15	.741 .17	.722 .16	.619 .12	.621 .14	.679 .15	.677 .16	.606 .10	.597 .15	.646 .11	.645 .13
	Adults n = 20	Mean SD	.483 .09	.477 .09	.507 .11	.504 .06	.452 .06	.443 .11	.474 .07	.465 .08	.434 .05	.418 .09	.451 .08	.437 .10
3	K n = 20	Mean SD	1.666 .24	1.525 .23	2.103 .26	1.963 .25	1.434 .19	1.304 .21	1.757 .24	1.681 .26	1.301 .17	1.219 .23	1.689 .20	1.664 .20
	Grade 6 n = 20	Mean SD	.812 .18	.822 .21	.888 .22	.834 .23	.715 .14	.768 .18	.720 .17	.764 .19	.699 .13	.671 .20	.741 .18	.724 .19
	Adults n = 20	Mean SD	.512 .10	.485 .12	.604 .13	.579 .14	.4519 .09	.468 .11	.527 .10	.524 .13	.432 .08	.417 .10	.507 .11	.499 .12
4	K n = 20	Mean SD	1.876 .28	1.735 .32	2.468 .36	2.386 .35	1.695 .26	1.504 .35	2.115 .34	2.141 .32	1.617 .21	1.469 .33	1.967 .34	1.894 .37
	Grade 6 n = 20	Mean SD	.922 .21	.838 .22	1.013 .24	.921 .23	.807 .18	.748 .23	.874 .22	.869 .21	.775 .15	.708 .20	.854 .21	.818 .21
	Adults n = 20	Mean SD	.606 .10	.543 .15	.715 .18	.693 .17	.542 .11	.493 .17	.641 .16	.610 .18	.509 .10	.496 .15	.601 .14	.583 .16
5	K n = 20	Mean SD	2.028 .32	1.581 .35	2.446 .38	2.290 .39	1.906 .30	1.545 .37	2.258 .34	2.121 .36	1.862 .25	1.504 .34	2.169 .34	2.018 .37
	Grade 6 n = 20	Mean SD	1.201 .22	1.031 .28	1.243 .30	1.223 .31	1.082 .18	.991 .29	1.152 .27	1.032 .28	1.004 .17	.947 .26	1.085 .28	1.052 .29
	Adults n = 20	Mean SD	.768 .16	.629 .17	.829 .16	.804 .18	.683 .15	.607 .18	.770 .19	.751 .19	.641 .15	.573 .15	.736 .17	.721 .16

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Three separate ANOVAS were conducted. They were based on the comparisons most revealing in distinguishing the various models. Furthermore, within each ANOVA, the important effects of age, number of possible differences, practice and their interaction were examined separately.

B. Same Versus D¹ Reaction Times

Comparison of response times for S stimuli and D¹ stimuli permit a decisive test of the entire class of serial self terminating models in those experiments in which $b_s = b_d$.¹ If $b_s = b_d$, the serial self terminating model does not permit S decisions to be longer than D¹ decisions. An ANOVA using individual subject mean correct judgment times as the dependent variable was conducted with Stimulus Format (S vs. D¹) and Days as within subject factors while Age Group and Number of Possible Differences were between subject variables, following Kirk (1968), Appendix B provides the ANOVA table for this analysis.

As is clearly evident from Table 3, the important main effect of Format is highly reliable with faster S than D¹ responses, $F(1,228) = 15.10$, $MS_e = .010$, $p < .01$. Furthermore, differences between S and D¹ were reliable for all groups, exceeding Tukey's HSD = .019. A significant effect of age was also found, $F(2,228) = 100.22$, $MS_e = .22$, $p < .01$, with reaction time decreasing as age increased. All differences between age groups were significant, exceeding Tukey's HSD = .023. A

¹ A single dimensional comparison (i.e. comparison of colour) resulting in an S decision is defined as b_s . If a single dimensional comparison results in a D decision, the comparison is designated b_d . When $b_s = b_d$, the isochronality assumption holds.

reliable effect of Number of Possible Differences was also demonstrated, with reaction time increasing as the number of possible differences increased, $F(3,228) = 7.53$, $MS_e = .22$, $p < .01$. All differences between groups 2D, 3D, 4D and 5D were significant, exceeding Tukey's $HSD = .010$. The main effect of days was also reliable, reaction times decreasing with practice, $F(2,456) = 54.24$, $MS_e = .007$, $p < .01$. All differences between Days were significant, exceeding Tukey's $HSD = .025$. Importantly, neither the effect of age nor practice interacted with any of the other factors.

C. Difference Responses

Examination of D response times depending on whether stimuli differed on all dimensions, (D^{ALL}) or on the most salient¹ dimension (D^{SAL}) as a function of age, practice and number of possible differences, is especially important in determining whether the processes underlying judgments of sameness and difference are age specific and whether practice tends to facilitate parallel processing. Accordingly, another ANOVA paralleling the preceding ANOVA but using D^{ALL} vs. D^{SAL} as the Stimulus Format, was conducted. The ANOVA table is provided in Appendix C.

As is clearly evident from Table 3, a reliable main effect of age was found, reaction times decreasing as age increased, $F(2,228) = 94.63$, $MS_e = .21$, $p < .01$. Reliable differences between all age groups were found, differences exceeding Tukey's $HSD = 0.45$. A significant main effect of the number of possible differences was also found, reaction times increasing

1 The most salient dimension is defined as the fastest D^1 response time. Admittedly, this definition is strong and it is not clear how it might be tested but it is not without precedent (cf. Egeth, 1966).

as the number of possible differences increased, $F(3,228) = 6.35$, $MS_e = .01$, $p < .01$. All differences between reaction times for groups 2D, 3D, 4D and 5D were reliable, exceeding Tukey's $HSD = .016$. A reliable effect of Format was also found, D^{ALL} being reliably faster than D^{SAL} , $F(1,228) = 7.27$, $MS_e = .22$, $p < .01$. Differences between D^{ALL} and D^{SAL} were significant for all groups, exceeding Tukey's $HSD = .016$. A significant main effect of practice was also demonstrated, reaction times decreasing with practice, $F(2,456) = 48.93$, $MS_e = .007$, $p < .01$. All differences between days were reliable, exceeding Tukey's $HSD = .025$.

For completeness, a comparable ANOVA using D^{ALL} vs. D^I as the Stimulus Format was conducted. The results, not too surprisingly, parallel those using D^{SAL} in detail. The ANOVA table is provided in Appendix D.

D. Theoretical Analysis

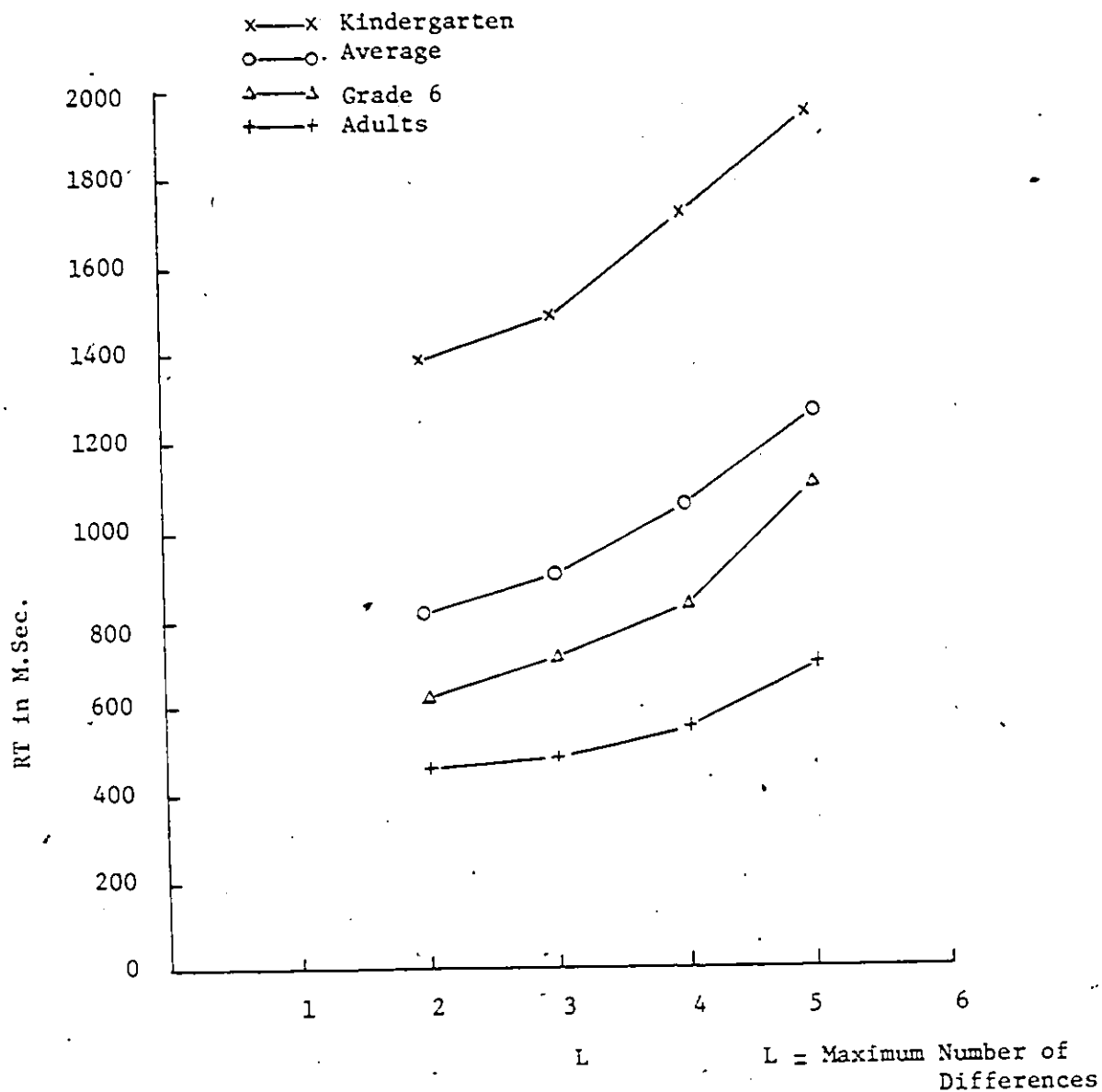
To delimit the variety of models and, in particular to examine the adequacy of both the original and the modified Bamber model, detailed analysis of S and D response times and their interrelationships are presented in this section.

i) S Reaction times. Figure 4 plots mean S reaction times, collapsing over days, as a function of L separately for each age group. As is evident from Figure 4, the plots show quadratic increases.

Polynomial regression analyses provide evidence of good quadratic fits for all groups, $R^2 = .9997$, $.9858$, and $.9942$ for the Adult, Kindergarten, and Grade 6 groups, respectively. The plots cannot be as adequately described by linear trends for the Adults and Grade 6 subjects, $R^2 = .8786$ and $.9361$, respectively. However, interestingly, a linear fit provides nearly as good a description as the quadratic fit for the Kindergarten

FIGURE 4

S Reaction Times for Kindergarten, Grade 6, and Adults and
Average S Reaction Times, for $L = 2$, $L = 4$ and $L = 5$



subjects, $R^2 = .9922$. Thus, overall these data fail to support the Bamber model and are in accord with the modified Bamber model.

ii) D Reaction times. Figures 5, 6, and 7 plot mean D response time as a function of the number of differences present, separately for each value of L, for the Adult, Grade 6, and Kindergarten subjects, respectively.

For every value of L for each group, D response times decrease as the number of differences present increases, permitting rejection of the strict parallel models and the conflict hypothesis (Jansen, 1974). As well, these plots show that S reaction times are always faster than D^1 responses, faster than D^2 responses in several instances, but never faster than D^3 responses. Since these plots were essentially the same for the three groups, more detailed analyses were performed after averaging over all subjects. The averaged plots are presented in Figure 8.

Least square regression analyses show that for each value of L, response times decrease linearly as the number of differences present increases. Furthermore, the slopes of these plots are surprisingly similar as is evident in Table 4 which summarizes these linear regression analyses. In addition, when $L = D$, the plot of D times against L appears to be quadratic, contrary to the original Bamber model but in accord with the modified Bamber model.

A Test of Isochronality in Bamber's (1969) Model

As discussed earlier, according to Bamber's (1969) model, S reaction times are given by

$$RT_S = h + L \cdot b_S$$

FIGURE 5 - ADULT

Adult D Reaction Times for $L = 2$, $L = 3$, $L = 4$ and $L = D$ when the Maximum Number of Differences Varies from 0 to 5

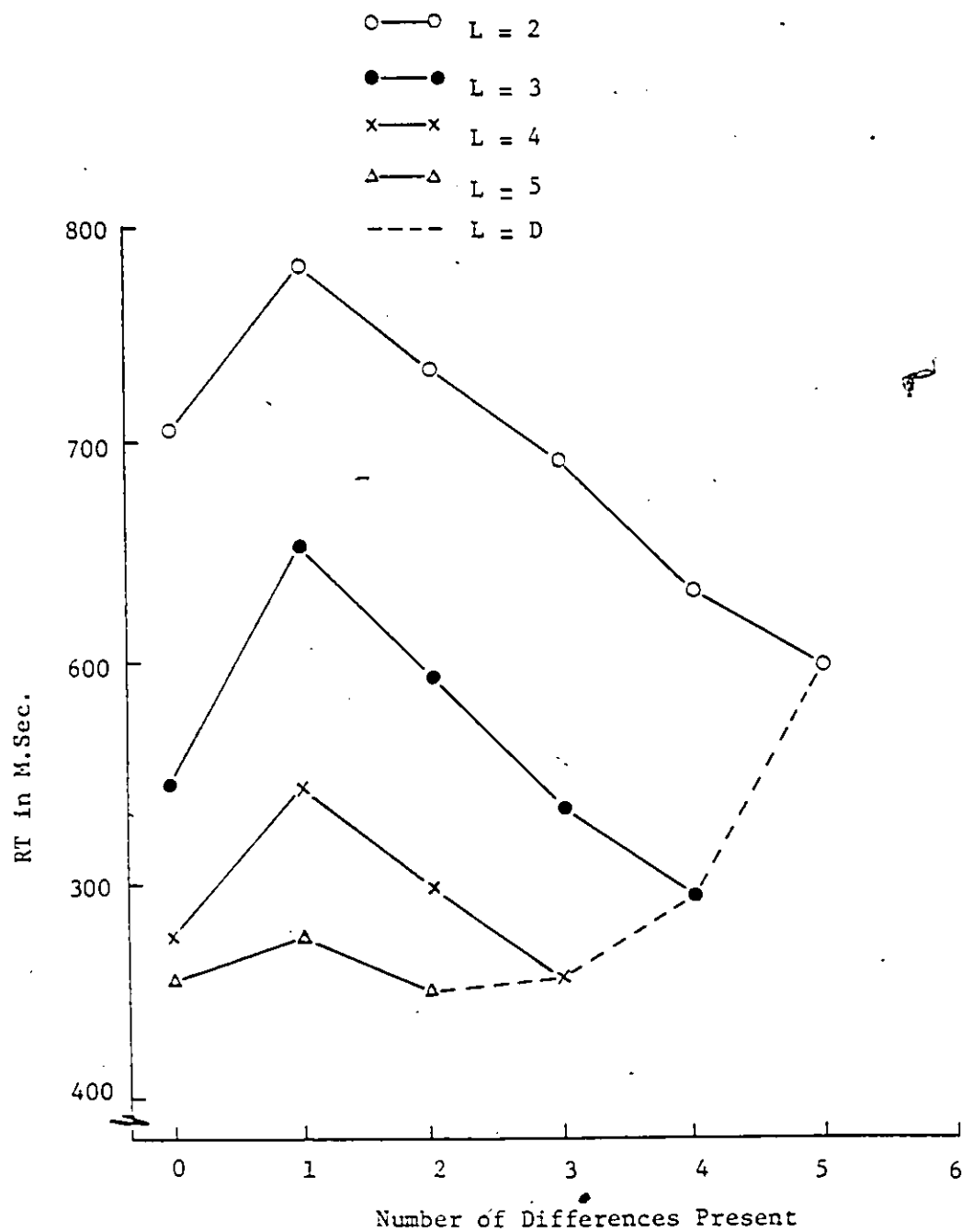


FIGURE 6 - GRADE 6

Grade 6 D Reaction Times for $L = 2$, $L = 3$, $L = 4$, $L = 5$
and $L = D$ when Maximum Number of Differences Varies from

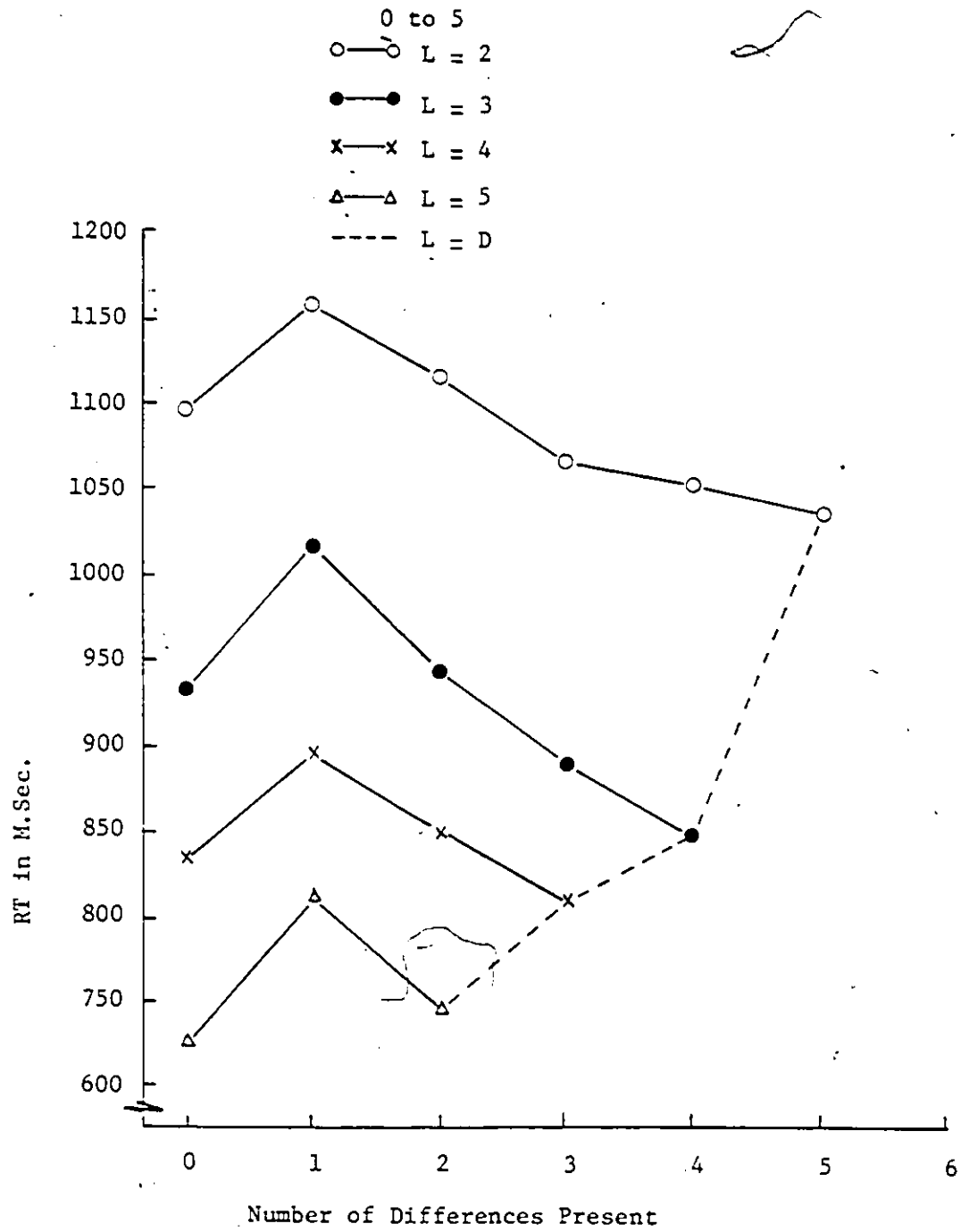


FIGURE 7 - KINDERGARTEN

Kindergarten D Reaction Times for $L = 2$, $L = 3$, $L = 4$, $L = 5$ and $L = D$
when Maximum Number of Differences Varies from 0 to 5

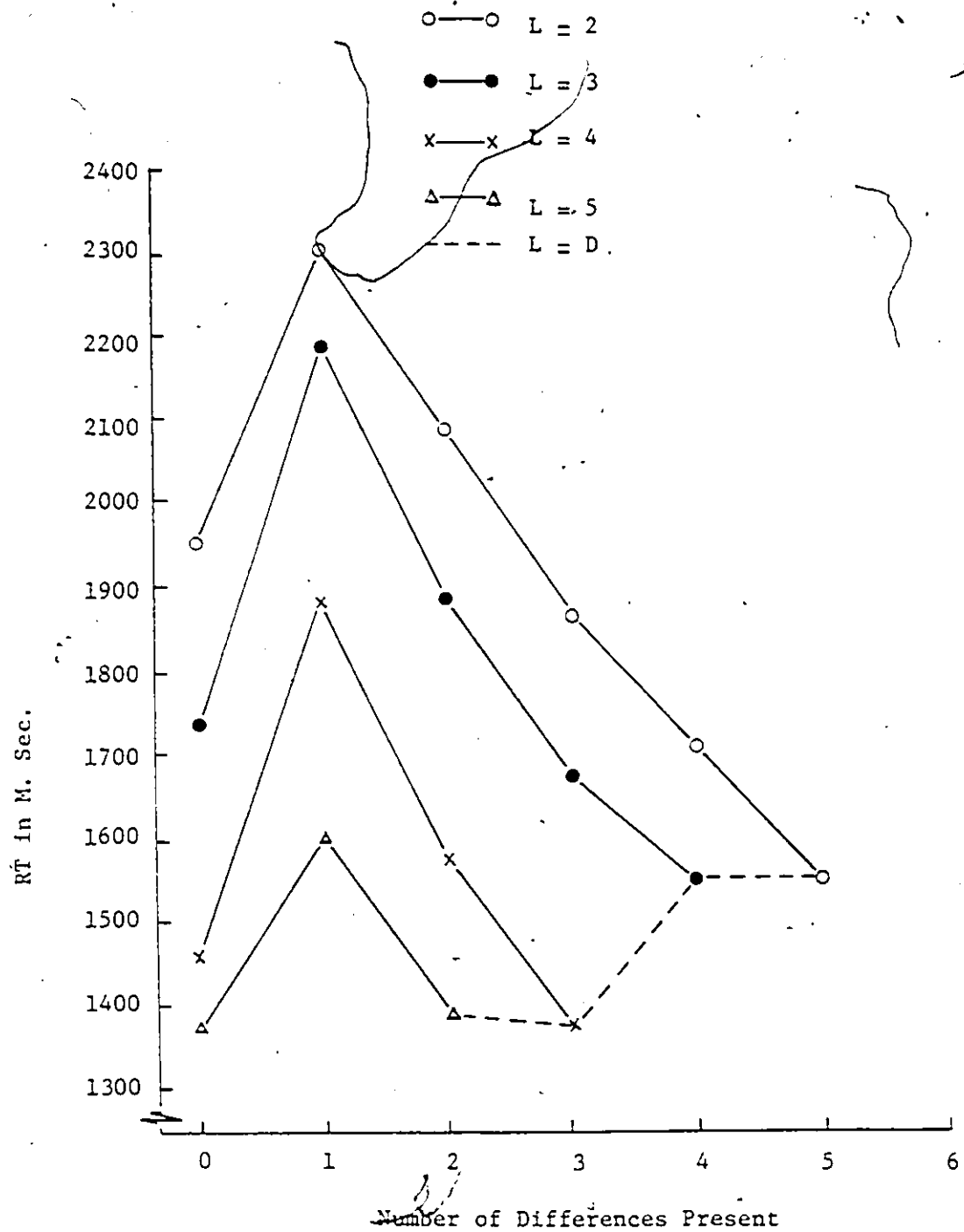


FIGURE 8 - AVERAGE

Average Reaction Times for $L = 2$, $L = 3$, $L = 4$, $L = 5$ and $L = D$ when the Maximum Number of Differences Varies from 0 to 5

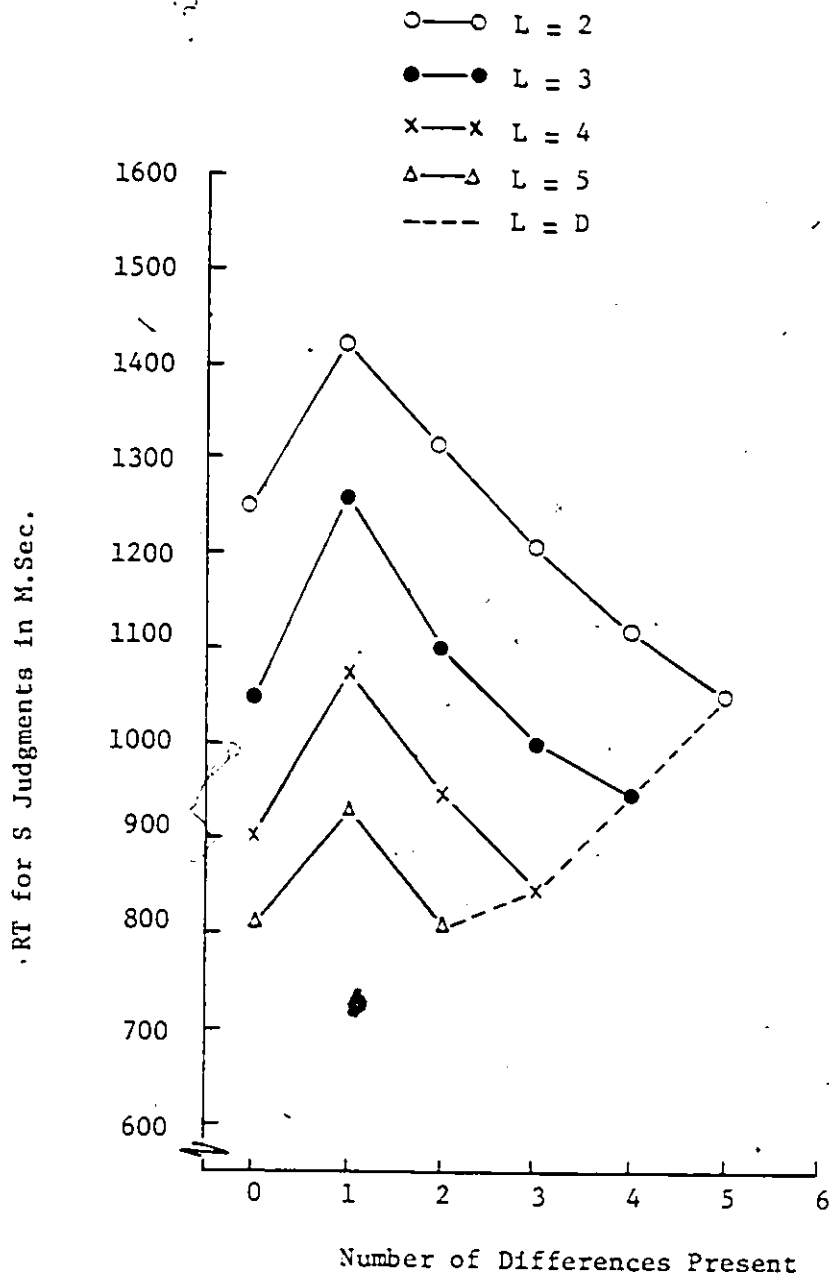


TABLE 6

Summary of Regression Analyses for D Reaction Times
as a Function of Number of Differences Present for

L = 3, 4 and 5

	L		
	3	4	5
R^2	.9923	.9677	.9905
Slope	-.115	-.105	-.097
Intercept	1.175	1.334	1.490

and D reaction times by

$$RT_D = h + b_d + b_s (L - D) / (D + 1)$$

where h denotes input and output times not involving decision components, b_s the time to determine sameness on each attribute and b_d the time to determine difference on each attribute. Estimates of the parameters, h , b_s and b_d were obtained by solving the systems of simultaneous linear equations, resulting from substituting the various values of D for each L into the above equations. For example, in the case $L = 2$, the three equations, $RT_S = h_s + 2 b_s$, $RT_D = h + b_d + b_s/2$ for $D = 1$, and $RT_D = h + b_d$ for $D = 2$; can be solved for h , b_d and b_s . Table 5 provides these estimates for each value of D and each group. While the estimates show considerable variability with varying values of L , it is clear that in every case b_s is substantially less than b_d rejecting the isochronality assumption.

E. Specific Stimulus Combinations

In order to determine whether or not the main findings were an artifact of averaging over the various stimulus combinations, response times were examined separately, for each specific stimulus combination. In addition, such analyses allowed determination of the dimensions on which comparisons were fastest. Figure 9 presents mean response times for specific stimulus combinations after averaging over age groups, since all preliminary analyses showed uniformity of findings over age levels.

Separate one way analyses of variance with repeated measures, with specific stimulus combinations were conducted for each value of L , after blocking on age level. Table 6 provides the usual ANOVA summary. In

TABLE 5

Single Dimension Comparison Times for S and D Judgments
and Neural Transmission Times According to Age Group and
Number of Possible Differences

	b_s	b_d	h
Group 2 D			
Adults	64 ms	118 ms	328 ms
Grade 6	106 ms	213 ms	422 ms
Kindergarten	450 ms	878 ms	480 ms
Group 3 D			
Adults	93 ms	267 ms	386 ms
Grade 6	109 ms	296 ms	534 ms
Kindergarten	343 ms	1254 ms	567 ms
Group 4 D			
Adults	73 ms	252 ms	292 ms
Grade 6	100 ms	379 ms	435 ms
Kindergarten	374 ms	1341 ms	422 ms
Group 5 D			
Adults	121 ms	507 ms	196 ms
Grade 6	136 ms	574 ms	415 ms
Kindergarten	412 ms	1647 ms	1070 ms

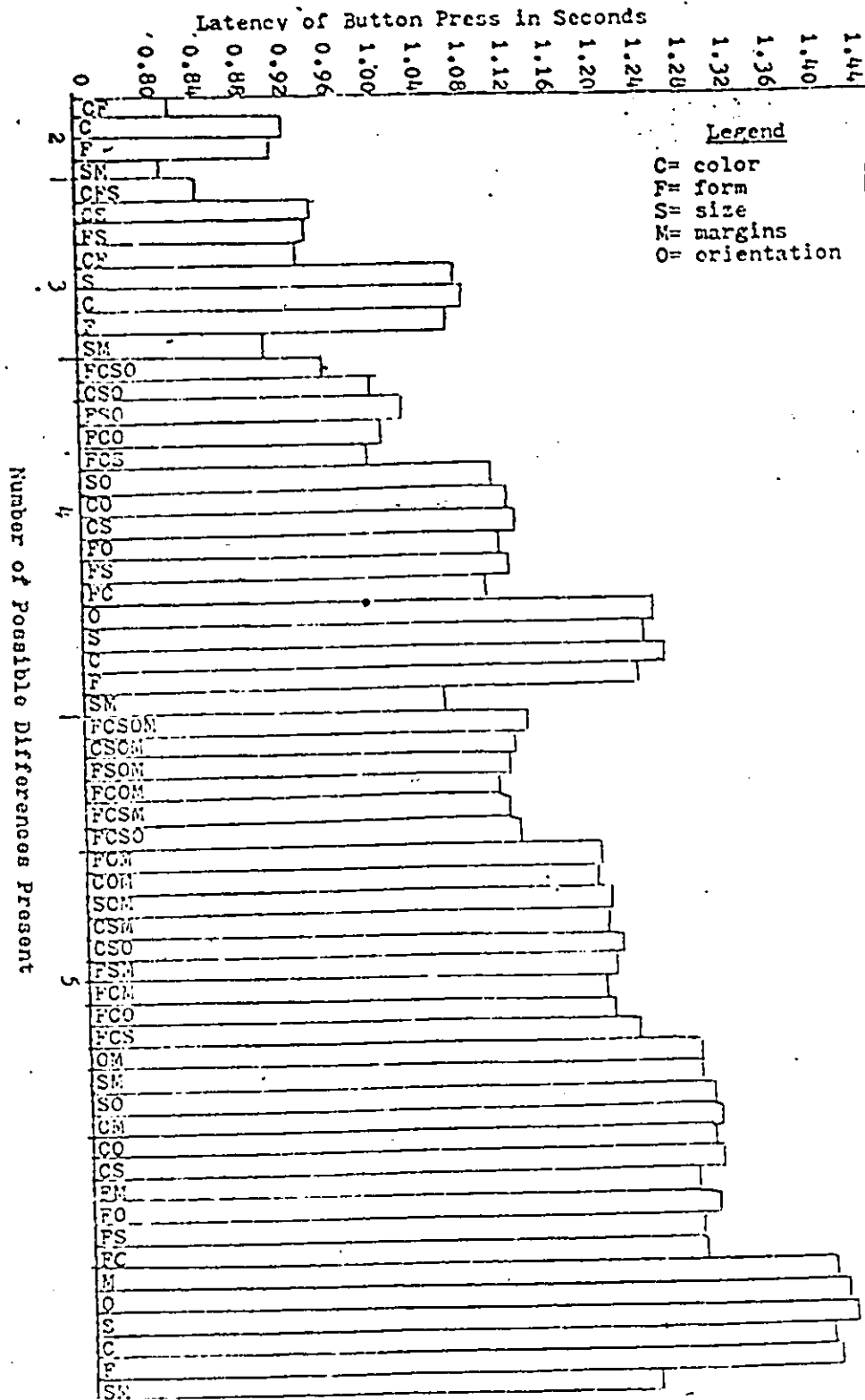


TABLE 6.
Summary of Analyses of Variance of Reaction Times for Specific Stimulus
Combinations for Groups in which 2, 3, 4, and 5 Maximum Differences were Possible

Source of Variation	2 Possible Differences				3 Possible Differences				4 Possible Differences				5 Possible Differences			
	Sum of Squares	df	Mean Squares	F	Sum of Squares	df	Mean Squares	F	Sum of Squares	df	Mean Squares	F	Sum of Squares	df	Mean Squares	F
Specific Stimulus Combination	0.600	3	0.27	13.50**	5.04	7	0.72	36.00**	36.48	15	2.43	81.07**	75.39	31	2.43	60.80**
Between Blocks	50.87	59	0.867	43.35**	76.73	59	1.30	65.03**	159.07	59	2.36	78.57**	497.96	59	8.44	211.00**
Residual	4.76	177	0.02		6.83	413	0.02		26.55	885	0.03		65.89	1829	0.04	

** p < .01

every case the effects of specific stimulus combination were highly reliable. Post-hoc Sheffé tests showed these differences were due exclusively to differences in D and that response times for specific stimuli did not differ within a particular level of D with significance levels set at $\alpha = .05$.

F. Errors

In the present study, 3.5% of responses were errors. Errors occurred most frequently for D¹ decisions (4.86%) and least frequently for S decisions (2.80%) with error frequency for D^{ALL} decisions falling between these two extremes (3.17%). No clear differences among age groups were noted (see Table 7) although the difference between error rates for S decisions and that for D¹ decisions was reliable ($t = 17.5$, $p < .01$). As the maximum number of differences increased, error rates also increased the error rate for Group 2D being 2.8%, for Group 3D, 3.2%, for Group 4D, 3.6% and for Group 5D, 4.4%. Again, no differences among age groups were noted (see Table 8).

TABLE 7
Percent Errors for S Judgments, D^I Judgments
and D^{ALL} Judgments

	S	D ^I	D ^{ALL}
Adults	2.80	4.81	3.16
Grade 6	2.93	4.84	3.13
Kindergarten	2.74	4.93	3.21
Average	2.80	4.86	3.17

TABLE 8Percent Errors for Groups 2 D, 3 D, 4 D and 5 D

	2 D	3 D	4 D	5 D
Adults	2.87	3.15	3.53	4.45
Grade 6	2.73	3.24	3.58	4.34
Kindergarten	2.80	3.21	3.69	4.41
Average	2.79	3.20	3.58	4.41

CHAPTER VI

Discussion

A. Models for Sameness-Difference

The results of the present study unambiguously demonstrate that S reaction times increased as the maximum number of possible differences, L, increased. Furthermore, this increase was found to be quadratic in every instance, providing important support for the modified Bamber model (cf., Prediction 8).

According to Prediction 1, D reaction time for the case $L = D$ should increase with L if subjects are processing stimuli according to the modified serial self terminating model but not for the original Bamber model. This prediction was confirmed in every case as was evident in Figure 5, for example.

Prediction 2 requires reaction times for stimuli with one difference present (D^1) to be longer than reaction times for stimuli with all differences present, (D^{ALL}) if subjects are processing stimuli according to all serial self terminating models. Analysis of variance showed, D^1 reaction times to be significantly longer than D^{ALL} reaction times, confirming Prediction 2.

According to Prediction 4, reaction times for stimuli with only the most salient difference present should also be longer than D^{ALL} reaction times for subjects processing stimuli according to any serial self terminating model. Again, ANOVA's showed this prediction to hold reliably in every case.

Prediction 5, from all serial self terminating models, requires reaction times for a particular value of D to increase if L increases. This prediction was confirmed for each value of D ($D = 1$, $D = 2$, $D = 3$, $D = 4$) in every case.

According to Prediction 6, all serial self terminating models require D reaction times for each particular value of L to decrease as D increases from $D = 1$ to $D = L$. The results of the present study show D reaction times for each value of L to decrease as D increases from $D = 1$ to $D = L$. In fact, this decrease was found to be linear with constant slope for all values of L .

Prediction 9 from Bamber's serial self terminating model requires S reaction times to be faster than D reaction times for low values of L whenever b_s (the time required for a single dimensional comparison resulting in a same decision on that dimension) is less than b_d (the time required for a single dimensional comparison resulting in a different decision on that dimension). Estimates of b_s and b_d (see Table 5) show that $b_s \neq b_d$ and $b_s < b_d$ for every level and each value of D in accord with Bamber, 1969, Hawkins, 1969, and Grill, 1971.

Thus the significantly faster S times can be explained easily by the fact that estimates of b_s are lower than the estimates of b_d using Bamber's original serial self terminating model. Consequently, it is not necessary to postulate a fast identity reporter. Therefore, the results of the present study do not contradict the results of the modified serial self terminating model. However, Bamber's original model

must be rejected for at least two reasons. First, it does not permit the rapid quadratic increase in D times with L when $L = D$. Second, the isochronality assumption receives no support as obtained estimates of b_s are clearly lower than the estimates of b_d .

The present results also permit rejection of a wide variety of parallel processing models. For example, according to Prediction 13, the parallel self terminating distributed model requires reaction time for D^{ALL} to be equal to reaction time for D judgments with the one most salient difference present (D^{SAL}). Since reaction times for D^{ALL} were significantly shorter than reaction times for D^{SAL} , it is clear that subjects do not appear to be processing stimuli according to a parallel self terminating distributed model. Similarly, Prediction 18 requires D^{ALL} to equal D^{SAL} if subjects are comparing stimuli according to a parallel self terminating constant model. As results of the present study reliably and uniformly indicate $D^{SAL} > D^{ALL}$, the parallel self terminating constant model can be rejected confidently.

B. Developmental Factors

As expected, older subjects responded more quickly, and a significant main effect of age was obtained. Importantly, however, age did not interact with any of the other experimental variables. Thus, the present experiment establishes the uniformity of process over age in sameness-difference judgments. Further, as discussed, the theoretical analysis of the

the results show this process to be best described by the modified serial self terminating model. Thus the present experiment shows, in accord with studies concerned with stimulus separability (Smith & Kemler, 1977; Kemler & Smith, 1978, 1979) that young children are able to compare individual dimensions of a multifeatured display separately.

The present findings are not in accord with those of Grill (1971) and Corcoran (1967) who showed that adult subjects switch from serial to parallel processing after sufficient extended practice. In the present study, the switch was hypothesized to occur developmentally with adults switching to parallel processing before children. Since the days variable did not interact with any other variable in the present study, practice merely increased the speed with which the serial process occurred and did not result in parallel processing. The reasons for this disparity are not clear and the large number of differences between the studies (e.g. number of practice trials and number of subjects) precludes speculation.

If response conflict were an important factor in the present study, then the longest reaction time would occur for $L = 4$, at $D = 2$. At $L = 5$, response conflict predicts longer reaction times for $D = 2$ than for $D = 1$. In the present study, D reaction time increased for every L as D increased from $D = 1$ to $D = L$, clearly rejecting response conflicts as a factor in same-different judgments, contrary to Jansen (1974) but in accord with

Egeth (1966), Nickerson (1967, 1973), Hawkins (1969), Grill (1971) and Bamber (1969, 1972).

C. Bias Factors

Support for the serial self terminating model with $b_s < b_d$ would be weakened, if, in the present study bias towards S judgments could be demonstrated. That is, the fast S reaction times demonstrated by the 2D, 3D and 4D groups might be due to bias toward the S response. However, this argument can be rejected for a number of reasons. On each day, every subject judged 96 stimulus pairs of which 48 required an S judgment and 48 required a D judgment. This served to eliminate bias due to more frequent repetition of a particular decision. In each group, however, the particular stimulus pairs which composed S stimuli had to be repeated more often than the particular stimulus pairs which composed D stimuli. If reaction time for a particular stimulus pair (e.g. two small red circles) declines as the number of judgments involving that pair increases, then S reaction times would be faster than D reaction times partly as a result of this bias. However this explanation receives no support from the available studies (Nickerson, 1973; Krueger, 1973).

Bias due to specific stimulus combination was also a possibility in this study. For example, reaction times for D slides with two differences present in group 3D must be obtained by averaging reaction times for CF (colour and form differences present), CS (colour and size differences present, and FS (form and size differences present)). If reaction times for any specific stimulus combination were significantly different from reaction times to other stimulus combinations included in the averaging

process, bias would result. With a smaller number of specific stimulus combinations,¹ a group of subjects could be run such that these subjects would judge D slides with only one specific stimulus combination (e.g. CF) used. In the present study, the number of specific stimulus combinations precludes the use of such a procedure. Thus, post hoc comparisons were made between reaction times for specific stimulus combinations for D slides with one difference present in group 2D, with one and with two differences present in group 3D, with one, with two and with three differences present in group 4D, and with one, two, three, and four differences present in group 5D. As no significant differences were found between specific stimulus combinations, bias due to specific stimulus combination becomes less likely.

Bias due to a specific effect of a difference in margin must also be considered. Overall, average S reaction times were faster than average

¹Specific stimulus combinations which would require separate groups are as follows:

Group 2D										
C	F									
Group 3D										
C	F	S								
CF	CS	FS								
Group 4D										
C	F	S	O							
CF	CS	CO	FS	FO	SO					
CFS	CFO	CSO	FSO							
Group 5D										
C	F	S	O	M						
CF	CS	CO	FS	FO	SO	OM	FM	SM	CM	
CFS	CFO	CSO	FSO	CFM	CSM	FSM	COM	FOM	SOM	
CFSO	CFSM	CFOM	FSOM	FSOM						

D reaction times in groups 2D, 3D; and 4D. While, D reaction times were faster than S reaction times in group 5D. However, differences in margins (M) occurred only in group 5D. Therefore, the possibility exists that faster D reaction times are due to a particular effect of the differences on M. For this bias to be significant, reaction times for specific stimulus combinations including M would have to be significantly different from reaction times for D slides which did not include M. Therefore, reaction times for 5D stimuli with one difference present were compared as follows:

$$M \text{ vs } \frac{C + F + S + O}{4}$$

Similarly, reaction times for 5D stimuli with two differences present were compared as follows:

$$CM \text{ vs } \frac{CF + CS + CO + FS + FO + SO}{6}$$

$$SM \text{ vs } \frac{CF + CS + CO + FS + FO + SO}{6}$$

$$FM \text{ vs } \frac{CF + CS + CO + FS + FO + SO}{6}$$

$$OM \text{ vs } \frac{CF + CS + CO + FS + FO + SO}{6}$$

Reaction times for 5D stimuli with three differences present were compared as follows:

$$CFM \text{ vs } \frac{CFS + CRO + CSO + FSO}{4}$$

$$CSM \text{ vs } \frac{CFS + CFO + CSO + FSO}{4}$$

$$FSM \text{ vs } \frac{CFS + CFO + SCO + FSO}{4}$$

$$COM \text{ vs } \frac{CFS + CFO + CSO + FSO}{4}$$

$$\text{SOM vs } \frac{\text{CFS} + \text{CFO} + \text{CSO} + \text{FSO}}{4}$$

$$\text{FOM vs } \frac{\text{CFS} + \text{CFO} + \text{CSO} + \text{FSO}}{4}$$

For 5D stimuli with four differences present, the following comparison was made:

$$\text{CFSO vs } \frac{\text{CFSM} + \text{CFOM} + \text{CSOM} + \text{FSOM}}{4}$$

For none of the above comparisons was a significant difference found.

Thus the possibility of M differences significantly affecting the relationship of S and D reaction times appears less likely.

D. Error Rates

Error rates in previous studies utilizing the "same-different" paradigm tended to be small. Some researchers such as Bamber (1969, 1972, 1975) controlled error rates by eliminating any subject whose error rate exceeded 3%. By this means overall error rates were kept between 1 and 2% (1.5% in Bamber's 1969 experiment and 1.4% in 1972). Other experimenters typically obtained error rates between 2% and 7%. The overall error rate of 3.5% in the present experiment was comparable to those previously obtained. Error rates for D judgments with all differences present at 3.17% were lower than error rates for D judgments with only one of the possible differences present 4.86%. This difference could be explained by the fact that detection of difference is more difficult when only one of the possible differences is present.

In the present study, the error rate increased as the maximum number of differences between stimuli increased being 2.79% for Group 2D, 3.20% for Group 3D, 3.58% for Group 4D, and 4.41% for Group 5D. Evidently,

since no clear differences among age groups occur in either Table 7 or 8, the differences in speed of processing among the groups cannot be ascribed to differences in speed-accuracy tradeoff strategy (see Pachella (1974) for a discussion of the speed-accuracy tradeoff). Similarly, since both error rates and response times increase monotonically over the conditions given in Tables 7 and 8, speed-accuracy tradeoff explanations of the major findings can be rejected.

E. An Alternative Formulation: Krueger's Model (1978)

According to Krueger's (1978) Noisy Operator model, subject process stimuli in a series of glances. A single glance is assumed to handle up to about four or five dimensions. Within glance, stimulus processing is assumed to be configurational, best described as a form of template processing.

Krueger's noisy operator model has been successfully applied in the case where stimulus material can be handled by a single glance. In this model, the within-glance configurational processing is accomplished in one to five passes, each of 200 ms duration.¹ During each pass, differences are counted and accumulated over several passes. If the accumulated number of differences exceeds a preset criterion, a D judgment results. An extremely low difference count, below another present criterion, results in an S judgment, while further passes are required if the difference count is between these two criterion points. To explain why S

¹This figure was arbitrarily set by Krueger after preliminary investigations.

judgments are faster than D judgments for multifeatured stimuli, Krueger introduces the concept of noise. In Krueger's "same-different" experiments (1970, 1973) as well as the majority of "same-different" experiments he examined, more errors occurred when S slides were displayed than when D slides were displayed. Accordingly, he maintains internal noise is more likely to make a same pair look different than to make a different pair look same, so pairs that look different must be rechecked (Krueger, 1978, p. 279). This rechecking of different pairs results in a slower reaction time for D judgments. Krueger demonstrates how a higher error rate for S slides can be predicted from his model. This model involves the assumption that the number of perceived differences for S slides and for D slides can be represented as a binomial distribution with the mean number of perceived differences being smaller for S slides than the mean number of differences for D judgments. As both the binomial distribution for S judgments and that for D judgments are positively skewed and must be so by the very nature of binomial distributions, incorrect responses to S slides will be more frequent than incorrect responses to D slides. Krueger (1978) and Nickerson (1978) maintain that the ability of Krueger's model to predict error rates is an important point in favour of the model.

However, in the present study, error rates were lower for S judgments than for D judgments. This pattern has also been found in other experiments, for example Bamber (1969, 1972), Grill (1971), Hawkins (1969) and Nickerson (1967) although it should be noted that the error rates are very low generally and perhaps do not provide a very sensitive test

of the model. Nevertheless, these findings question the applicability of the model as fitted by Krueger (cf., Appendix A, p. 302). It is possible to salvage the model by postulating biased preset criteria on the number of differences attribute. In fact, variations in criteria locations are indistinguishable from changes in the form of the prototypical same and different distributions.

To develop and illustrate the noisy operator model, Krueger (1978) used data from other experiments reported in Shapiro (1977) and Shapiro and Krueger (1977). In each of these experiments, the mean S and D reaction times are known. Krueger assumed that the number of perceived featural mismatches were binomally distributed. Assuming a pass time of 200 msec and using the formulae in Appendix A, Krueger fit the model to the reaction time distributions. However, the model encountered difficulties in predicting too low an error rate. In conclusion, while Krueger's model is effective in describing in considerable detail a wide variety of details of same different judgments, probabilities, and response times, it has done so under a host of arbitrary and at times unclear assumptions.

F. A Proposed Study

Fast S reaction times are predicted from the serial self terminating model when $b_s < b_d$ and L is low. Results of the present study confirm this prediction. However, Prediction 9 also states that D reaction times will be faster than S reaction times for high value of L. The value of L required to eliminate fast reaction times will depend on the relative values of b_s and b_d .

A further test of Prediction 9 should be undertaken to demonstrate

faster D reaction times for high L. In this proposed experiment, either adults or children could be used as subjects without loss of generality since the present study shows young children's "same-different" judgments can be described by the same model as that for the adults. This proposed study would require a maximum value of L of 8 to 10 at the very least. Since the number of possible stimulus combinations doubles with each increase in L, use of a computer randomly to select specific combinations for use in this study might be advisable. Further simplification might be achieved by elimination of some values of L. For example, a study could use $L = 2, L = 3, L = 9, L = 10$ or $L = 2, L = 4, L = 6, L = 8, L = 10$. By this means, far fewer experimental groups and subjects would be necessary. However, an experimenter who eliminated some values of L would risk eliminating exactly those values of L in which the switch from fast same to fast different occurred. In order to overcome this difficulty an experimenter might plan two high L experiments. The first experiment could be utilized for locating the values of L in which the switch from fast S to fast D occurs. For example, $L = 4, L = 8, L = 12$ and $L = 16$ might be used. A second experiment could then be designed to explore relative S and D reaction times in with more finely spaced values of L in this region. For example, if S reaction times were faster for $L = 8$ and slower for $L = 12$, this second experiment might utilize $L = 8, L = 9, L = 10, L = 11$ and $L = 12$. For these proposed experiments, the experimental parameters, e.g. apparatus and instructions, for example, should be identical, or closely similar to those of the present study. Perhaps, using either letter or number strings would permit stimuli with

sufficient dimensions for these experiments.

G. Practical Implications of the Present Study

In the present study, young children appeared to be using a serial self terminating process of comparison as did older children and adults. This implies that young children are able to compare stimuli on one attribute at a time in the "same-different" task just as in the concept learning task used by Kemler and Smith, 1979. These findings have implications for the design of programmes in readiness and early reading in Kindergarten and Grade 1. In many readiness and early reading tasks, children are required to detect sameness and difference. The stimuli used, coloured and geometric shapes, single letters, short syllables or words, may differ along one or more dimensions. If children are able to process stimuli according to a serial self terminating process of comparison, they could compare the stimuli on one dimension or attribute at a time. Thus this view suggests that, since stimuli can be decomposed into analyzable separable components, children should be taught to notice fine details (e.g. b, the ball on the right side, d the ball on the left side) in teaching letter identification. Furthermore, it also follows that children should be trained to examine the detail of each letter then identify the letter, proceeding from letter to letter, left to right in a serial process of comparison, in word comprehension. In fact, in a phonics based reading programme, exactly this process occurs (Engelman, S. and Bruner, E.C., 1974). The child examines each letter sequentially from left to right, noting the details of each letter and identifying the letter by its sound. In a later stage, these sounds are synthesized to form a word.

If a young child is capable of processing the individual dimensions within a multidimensional stimulus and if these are processed serially, the skills demanded by a phonics based reading approach are readily accessible.

In contrast, if a young child were unable to process individual dimensions, and tended towards parallel or holistic processing of stimuli, the reading approach discussed above would be less natural and therefore more difficult for the child. Furthermore, if young children tended to utilize this parallel or holistic approach and older children did not, then the sequential and phonetic reading approach first discussed would be more appropriate for the later primary grades. Holistic or parallel processing would suggest a reading approach in which words were identified globally by their general appearance focussing on several aspects of the word at once (e.g. number of tall letters, position of tall letters, identity of initial consonant) rather than focussing on one letter after another.

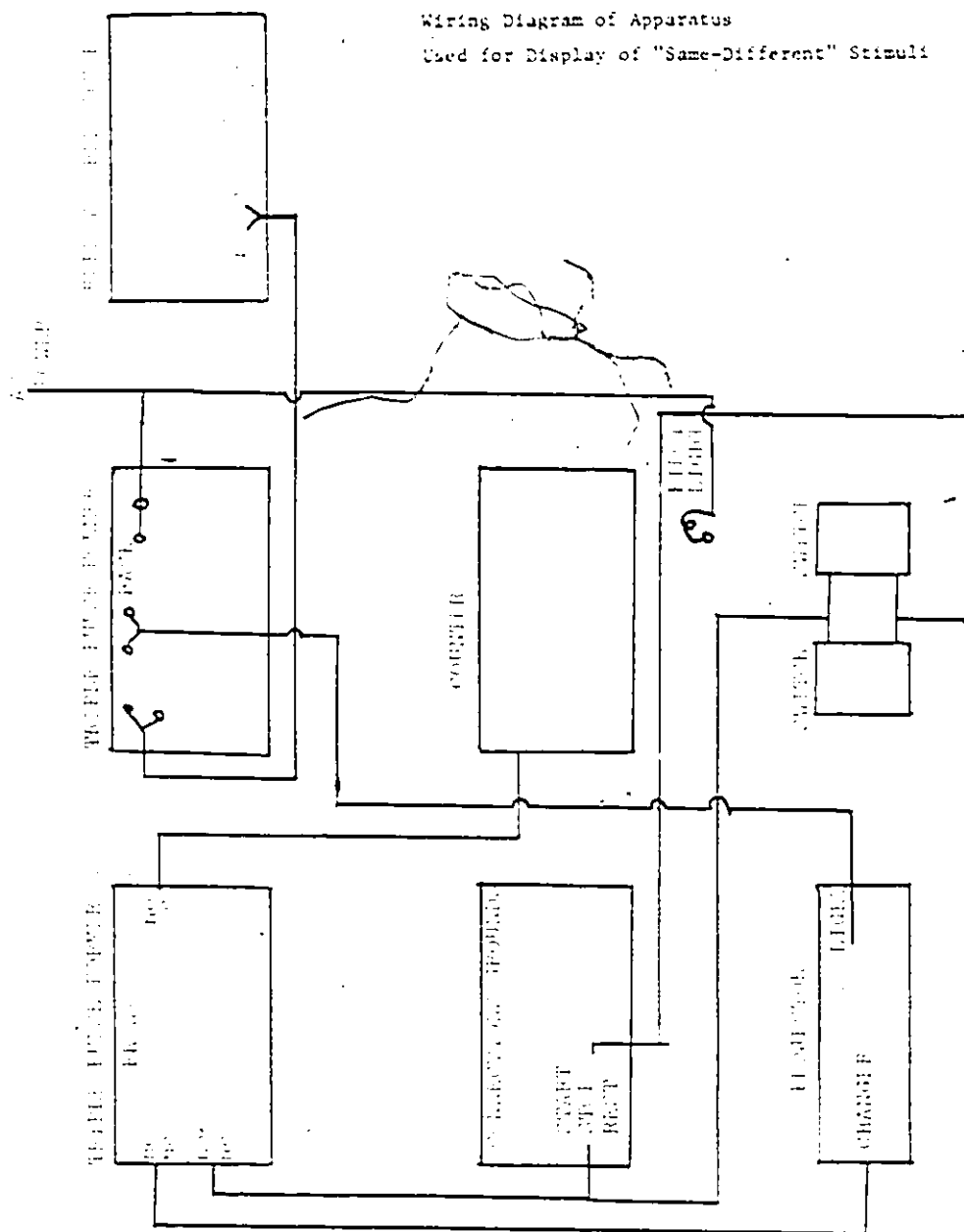
Furthermore, children's apparent ability to process stimuli according to a serial self terminating model and the similarity of this processing pattern to that of adults suggests the importance of the ability to detect fine detail and the ability to process and remember details in the correct sequence. Thus children should not be trained to notice and process several aspects of a stimulus at the same time. This ability would assume adult parallel processing as a desirable goal for children. In contrast, children should be specifically trained to detect differences between stimuli even when only one of the possible differences is present. Furthermore, exercises requiring detection of differences between stimuli in sequence, and reproduction of these differences in the correct order,

would be useful in developing those skills necessary to the development of reading ability.

APPENDIX A

FIGURE 10

Wiring Diagram of Apparatus
Used for Display of "Same-Different" Stimuli



APPENDIX B

Table 9

Summary of Analysis of Variance of Reaction Times for S and for D¹
Judgments According to Age, Number of Stimulus Differences and Days

Sources of Variation	Sum of Squares	df	Mean Squares	F-ratio
Between Subjects	99.624	239		
Age	44.096	2	22.05	100.22**
Number of Possible Differences	4.970	3	1.66	7.53**
Age X Number of Possible Differences	.41	6	.07	.31
Subject Within Groups	50.148	228	.22	
Within Subjects		1200		
Format	.15	1	.151	15.100**
Age X Format	.02	2	.01	1.00
Format X Number of Possible Differences	.02	3	.01	.67
Number of Possible Differences X Age X Format	.006	6	.001	.10
Format X Subject Within Groups	2.54	228	.01	
Days	.75	2	.38	54.29**
Age X Days	.015	4	.0038	.54
Number of Possible Differences X Days	.020	6	.0033	.47
Age X Number of Possible Differences X Days	.03	12	.0025	.36
Days X Subject Within Groups	3.21	456	.007	
Format X Days	.06	2	.03	.00001
Age X Format X Days	102.69	4	25.67	.01
Format X Number of Possible Differences X Days	184.56	6	30.76	.096
Age X Format X Number of Possible Differences X Days	4.36	12	.36	.0001
Format X Days X Subjects Within Groups	1670239.42	456	3362.81	

** p < .01

APPENDIX C

TABLE 10

Summary of Analysis of Variance of Reaction Times for D Judgments
with All Differences Present and for D Judgments with the One Most

Salient Difference Present

Sources of Variation	Sum of Squares	df	Mean Squares	F-ratio
Between Subjects	92.01	239		
Age	39.74	2	19.87	94.63**
Number of Possible Differences	4.00	3	1.33	6.35**
Age X Number of Possible Differences	.39	6	.06	.309
Subject Within Groups	47.88	228	.21	
Within Subjects		1200		
Format	.08	1	.08	7.27**
Age X Format	.019	2	.01	.86
Format X Number of Possible Differences	.024	3	.01	.73
Number of Possible Differences X Format X Age	.007	6	.001	.11
Format X Subject Within Groups	2.51	228	.011	
Days	.63	2	.31	48.93**
Age X Days	.017	4	.004	.66
Number of Possible Differences X Days	.020	6	.003	.52
Age X Number of Possible Differences X Days	.047	12	.0039	.61
Days X Subject Within Groups	2.92	456	.0064	
Format X Days	.07	2	.04	.00001
Age X Format X Days	101.77	4	25.44	.0069
Format X Number of Possible Differences X Days	190.27	6	31.71	.0086
Age X Format X Number of Possible Differences X Days	4.42	12	.37	.0001
Format X Days X Subject Within Groups	1681463.52	456	3687.42	

** p < .01

APPENDIX D

TABLE 11

Summary of Analysis of Variance of Reaction Times for D Judgments
with All Differences Present and for D Judgments with Difference
Present

Sources of Variation	Sum of Squares	df	Mean Square	F-ratio
Between Subjects	96.780	239		
Age	42.99	2	21.50	97.73**
Number of Possible Differences	4.21	3	1.40	6.36**
Age X Number of Possible Differences	.40	6	.07	.32
Subject Within Groups	49.18	228	.22	
Within Subjects		1200		
Format	.09	1	.09	8.18**
Age X Format	.018	2	.01	.91
Format X Number of Possible Differences	.019	3	.01	.91
Number of Possible Differences X Format X Age	.006	6	.001	.09
Format X Subject Within Groups	2.52	228	.011	
Days	.71	2	.36	53.73**
Age X Days	.016	4	.004	.60
Number of Possible Differences X Days	.02	6	.003	.45
Age X Number of Possible Differences X Days	.03	12	.0025	.37
Days X Subject Within Groups	3.04	456	.0067	
Format X Days	.06	2	.03	.00001
Age X Format X Days	103.57	4	25.89	.01
Format X Number of Possible Differences X Days	187.49	6	31.25	.01
Age X Format X Number of Possible Differences X Days	4.57	12	.38	.0001
Format X Days X Subject Within Groups	1672496.89	456	3667.76	

** $p < .01$

REFERENCES

- Bamber, D. Reaction time and error rates for "same"- "different" judgments of multidimensional stimuli. Perception and Psychophysics, 1969, 6(3), 169-174.
- Bamber, D. Reaction times and error rates for judging nominal identity of letter strings. Perception and Psychophysics, 1972, 12(4), 321-326.
- Bamber, D., Herder, J., and Tidd, K. Reaction times in a task analogous to Same-Different judgments. Perception and Psychophysics, 1975, 18, 321-327.
- Beller, H.K. Parallel and serial stages in matching. Journal of Experimental Psychology, 1970, 84(2), 213-219.
- Bertelson, P. Sequential redundancy and speed in a serial two choice responding task. Quarterly Journal of Experimental Psychology, 1961, 13, 90-102.
- Bertelson, P. S-R relationships and reaction times to new vs. repeated signals in a serial task. Journal of Experimental Psychology, 1963, 65, 478-484.
- Bertelson, P., & Rankin, A. Reaction times to new vs. repeated signals in a serial task as a function of response-signal time interval, Acta Psychologica, 1965, 25, 132-136.
- Biederman, I., & Checkovsky, S.F. Processing redundant information. Journal of Experimental Psychology, 83(3), 486-490.
- Bindra, D., Williams, J., & Wise, J. Judgments of sameness and difference, experiments on decision time, Science, 1965, 1625-1627.
- Bindra, D., Donderi, D., & Nishisato, N. Decision latencies of same and different judgments. Perception and Psychophysics, 1968, 3, (28), 121-129.

- Bogartz, R.S. Sequential dependencies in children's probability learning. Journal of Experimental Psychology, 1965, 70(4), 365-370.
- Bogartz, R.S. Extension of a theory of predictive behavior in young children to the effects of intertrial interval duration. Psychonomic Science, 1967, 8(12), 521-522.
- Bogartz, R.S., and Witte, R.L. On the locus of stimulus familiarization effect in young children. Journal of Experimental Child Psychology, 1966, 4, 317-331.
- Boring, E.G. History, Psychology, and Science. John Wiley & Sons Inc., New York: 1963.
- Brian, C.R., and Goodenough, F.L. The relative potency of colour and form perception at different ages. Journal of Experimental Psychology, 1929, 197-213.
- Cantor, G.N. Stimulus familiarization effect and the change effect in children's motor task behavior. Psych. Bulletin, 1969, 71, 144-160.
- Cantor, G.N., and Cantor, J.H. Effects of conditioned stimulus familiarization on instrumental learning in children. Journal of Experimental Child Psychology, 1964, 1(1), 71-78.
- Corballis, M.C., Lieberman, W., and Bindra, D. Discriminability and central intermittency in same-different judgments. Quarterly Journal of Experimental Psychology, 1968, 20, 51-61.
- Corcoran, D. Serial and parallel classification. British Journal of Psychology, 1967, 58, 3 and 4, 197-202.
- Coltheart, M., and Curthoys, I. Short term recognition of memory for pitch: Effect of a priori probability on response times and error rates. Perception and Psychophysics, 1968, 4(2), 85-88.

- Derks, P.L. Visual recognition of similarity and identity. Journal of Experimental Psychology, 1971, 95(1), 237-239.
- Donderi, D., and Case, B. Parallel visual processing: Constant same-different decision latency with two to fourteen shapes. Perception and Psychophysics, 1970, 8(58), 373-375.
- Downing, B. Response probabilities and same-different reaction time. Perception and Psychophysics, 1970, 9(2B), 213-214.
- Downing, B.D., and Gossman, J.R. Parallel processing of multi-dimensional stimuli. Perception and Psychophysics, 1970, 8(1), 57-60.
- Egeth, H. Parallel versus serial processes in multi-dimensional stimuli. Perception and Psychophysics, 1966, 1, 245-252.
- Eichelman, W.H. Stimulus and response repetition effects for naming letters at two response intervals. Perception and Psychophysics, 1970a, 2, 94-96.
- Eichelman, W.H. Familiarity effects in the stimulus matching task. Journal of Experimental Psychology, 1970b, 86(2), 275-282.
- Engleman, S., and Bruner, E.C. Distar Reading, Science Research Associates, 1974.
- Entus, A., and Bindra, D. Common features of the repetition and same-different effects in reaction time experiments. Perception and Psychophysics, 1970, 7(3), 143-148.
- Estes, B.W. Judgment of size in relation to geometric shape. Child Development, 1961, 32, 277-286.
- Falmagne, J.C. Stochastic models for choice reaction time with applications to experimental results. Journal of Mathematical Psychology, 1965, 13, 77-124.

- Fantz, R.L. Pattern vision in young infants. Psychological Review, 1958, 8, 43-47.
- Fantz, R.L. Pattern vision in newborn infants. Science, 1963, 140, 296-297.
- Fechner, G.T. Elements of psychophysics. Translated by Adler, H.E., edited by Howes, D.H., and Boring, E.G., Holt Rhinehart & Winston, New York: 1966.
- Gaines, R., and Little, A.C. Developmental colour perception. Journal of Experimental Psychology: Human Perception and Performance, 1975, 1, 265-286.
- Garner, W.R. The stimulus in information processing. American Psychologist, 1970, 25, 350-358.
- Garner, W.R. The processing of information and structure. Lawrence Erlbaum, Potomac, Md.: 1974.
- Gellerman, L.W. Form discrimination in chimpanzees and two-year-old children. Journal of Genetic Psychology, 1933, 42, 1-50.
- Gibson, E.J., and Olum, V. Experimental methods of studying perception in children. Mussen, P.H. (Ed.), Handbook of research methods in Child Development. J. Wiley & Sons, New York: 1960.
- Gindes, M., and Barten, S. The development of equivalence rules for visual configurations. Journal of Experimental Child Psychology, 1977, 24, 11-23.
- Graham, V., Jackson, T.A., and Long, L. Generalization of the concept of middle-ness. Journal of Genetic Psychology, 1944, 65, 227-237.
- Grill, D. Variables influencing the mode of processing of complex stimuli. Perception and Psychophysics, 1971, 10, 51-57.

Hawkins, H.L. Parallel processing in complex visual discriminations.

Perception and Psychophysics, 1969, 5, 56-64.

Huang, I. Abstraction of colour and form in children as a function of the stimulus object. Journal of Genetic Psychology, 1945, 66, 59-62.

Hyman, R. Stimulus information as a determinanat of reaction time.

Journal of Experimental Psychology, 1952, 45, 188-196.

James, W. Principles of psychology. Dover Publications Inc., New York:

1950. First published, Henry Holt & Company, New York: 1890.

Jansen, L.E. A Development Study of Reaction Times for Same-Different Judgments. Unpublished MA thesis, 1974.

Kagan, J., and Lemkin, J. Form, colour and size in children's conceptual behavior. Child Development, 1961, 32, 25-28.

Kemler, L.B., and Smith, D.G. Is there a developmental trend from integrality to separability in perception. Journal of Experimental Child Psychology, 1978, 26, 498-507.

Kemler, L.B., and Smith, D.G. Assessing similarity and dimensional relations: Effects of integratity and separability on the discovery of complex concepts. Journal of Experimental Psychology: General, 1979, 108(2), 133-150.

Kirk, R.E. Experimental design: Procedures for the Behavioral Sciences.

Brooks/Cole Publishing Company, Belmont, California: 1968.

Krinchik, J. The probability of a signal as a determinant of reaction time. Acta Psychologica, 1969, 30, 27-36.

Krueger, L.E. Effect of bracketing lines on speed of same-different judgment of two adjacent letters. Journal of Experimental Psychology, 1970, 84(2), 324-330.

- Krueger, L.E. Effect of irrelevant surrounding material on speed of same-different judgment of two adjacent letters. Journal of Experimental Psychology, 1973, 98(2), 251-259.
- Krueger, L.E. A theory of perceptual matching. Psychological Review, 1978, 84, 278-304.
- Ling, B.C. Form discrimination as a learning cue in infants. Comparative Psychology Monographs, 1942, 17(2).
- Locke, J. An essay concerning human understanding. Yolton, J.W. (Ed.), J.M. Dent & Sons Ltd. London: 1961.
- Lockhead, G.R. Effects of dimensional redundancy. Experimental Psychology, 1966, 72, 94-104.
- Lockhead, G.R. Processing dimensional stimuli. Psychological Review, 1972, 410-419.
- Marsden, R.E. A study of the early colour sense. Psychological Review, 1903, 10, 37-47.
- McDougall, R. An investigation of the colour sense of two infants. British Journal of Psychology, 1906-1908, 2, 338-352.
- Meyer, E. Comprehension of spatial relations in preschool children. Journal of Genetic Psychology, 1940, 57, 119-151.
- Miller, J.D. Multidimensional same-different judgments: Evidence against independent comparisons of dimensions. Journal of Experimental Psychology, 1978, 4(3), 411-422.
- Neisser, V. Cognitive Psychology. A Appleton-Century-Crofts. New York: 1967.
- Nickerson, R. Response times for 'same'-'different' judgments. Perceptual and Motor Skills, 1965, 20, 15-24.

- Nickerson, R. Same-'different' response times with multi-attribute stimulus differences. Perceptual and Motor Skills, 1967, 24, 543-554.
- Nickerson, R.S. Short term retention of visually presented stimuli: some evidence of visual encoding, Acta Psychologica 1976, 40, 153-162.
- Nickerson, R. 'Same'-'different' reaction times: A model and a preliminary test. Acta Psychologica, 1969, 30, 257-275.
- Nickerson, R.S. Frequency, recency and the reaction time repetition effect on same and different response times. Journal of Experimental Psychology, 1973, 101, 330-336.
- Nickerson, R.S. On the time it takes to tell things apart, Attention and Performance VII. Requiem, J. (Ed.). Lawrence Erlbaum, Hillsdale, N.J.: 1978.
- Pachella, R.G. The interpretation of reaction-time in information processing research. In B.H. Kantowitz (Ed.) Human information processing: Tutorials in performance and cognition. Potomac, Md., Erlbaum, 1974.
- Peckham, R.H. Visual discrimination in preschool children. Child Development, 1933, 4, 292-297.
- Peters, W. Die Entwicklung von Wahrnehmungsleistungen beim Kind. Zeitschrift Psychologische Physiologische, Sinnesorg, 1927, 103, 129-184.
- Petrusic, W. Personal communication, 1974.
- Posner, M.I., and Mitchell, R.F. Chronometric analysis of classification. Psychological Review, 1967, 5, 394-409.

Posner, M.I., Boies, S.J., Eichelman, W.H., and Taylor, R.L.

Retention of visual and name codes of single letters. Journal of Experimental Psychology, 1969, 79(No. 1, Part 2), 1-16.

Preyer, W. The mind of the child: Part II: The development of the intellect. Brown, H.W., (Trans.). New York: Appleton, reprinted edition, 1901.

Rajalakshmi, S., and Jeeves, L. Changes in tachiscopic form perception as a function of age and intellectual status. Journal of Gerontology, 1963, 18, 275-278.

Remington, R.J. Analysis of sequential effects in choice reaction times. Psychology Bulletin, 1969, 67, 250-257.

Sekular, R.W., and Abrams, M. Visual sameness: A choice time analysis of pattern recognition processes. Journal of Experimental Psychology, 1968, 77, 232-238.

Selfridge, O.G., and Neisser, V. Pattern recognition by machine. Scientific American, 1963, 203, 60-68.

Silverman, W.P., and Goldberg, S.L. Further confirmation of same vs. different processing. Differences, Perception and Psychophysics, 1975, 17, 189-193.

Smith, L.B., and Kemler, D.G. Developmental trends in free classification. Journal of Experimental Child Psychology, 1977, 24, 352-362.

Staples, R. The responsiveness of infants to colour. Journal of Experimental Psychology, 1932, 15, 119-141.

Sternberg, S. High speed scanning in human memory. Science, 1966, 153, 652-654.

- Tversky, B. Pictorial and verbal encoding in a short term memory task. Perception and Psychophysics, 1969, 6, 225-232.
- Tversky, B. Pictorial and verbal encoding in preschool children. Developmental Psychology, 1973, 8, 149-153. *
- Uhr, L. Pattern recognition. Computers as models for form perception. Psychological Bulletin, 1963, 60(1), 40-73.
- Valentine, C.W. The colour perception and colour preference of an infant during its fourth and eighth months. British Journal of Psychology, 1913-1914, 6, 363-386.
- Vinake, W.E. The investigation of concept formation. Psychological Bulletin, 1951, 48, 1-31.
- Welch, L. The development of discrimination of form and area, Journal of Psychology, 1939, 7, 37-54.
- White, S.H. Training and timing in the generalization of a voluntary response. Journal of Experimental Psychology, 1965, 69, 269-275.
- Williams, J.D. Effects of practice with controlled stimulus pairs on same-different judgments, Journal of Experimental Psychology, 1972, 96, 73-77.