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ABSTRACT

THE USE OF HIERARCHICAL FEATURES IN OBJECT RECOGNITION IN PIGEONS

By

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Two experiments were designed and performed to examine the application of Palmer's (1977) model of object recognition to animals. The hierarchical structural organization of features was studied with stimuli constructed on the basis of Gestalt principles of perceptual organization. Initially, pigeons discriminated between two different orientations of a two-dimensional line drawing for both experiments. Following acquisition, positive and negative generalization tests were performed using sets of parts of the training stimuli in experiment one, and single parts in experiment two. In experiment one, the pigeons responded significantly more to the set of parts having high proximity ratings than the set having low proximity ratings during the positive generalization test. In the second experiment, the pigeons did not respond differentially to single parts having differing proximity ratings. This may have been due to the large reduction in contour of the single part probes. It may be concluded that pigeons organize features into hierarchical structural units.

This dissertation is dedicated to the memories of my mother and my son who were both committed to the Lord's care this year. It is also dedicated to my wife whose continued support, caring, faith and love have made the difference for me.

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Table of Contents

List of Tables

List of Figures

Introduction

The Comparative Approach

Comparative psychology has been faced with explaining both the similarities and differences amongst the behaviors of different species. This is similar to the paradox of diversity and unity of life which Darwin attempted to resolve through his theory of evolution. Indeed Darwin has frequently been rendered as the father of comparative psychology (Boakes, 1984; Domjan, 1987; Stebbins, 1990; Macphail, 1990). While the historical roots of comparative psychology grew in the fertile soil of learning theory spreading rapidly from Rommanes to C. L. Morgan, thence to America and E. L. Thorndike who was a forefather of behavioral psychology, it ironically lost much of its comparative flare soon coming to be the study of cats, rats, and pigeons. It has more recently undergone a major transformation as reviewed by Domjan and Galef (1983), discussed by Shettleworth (1983), clearly influenced by Garcia (1981), and described by Seligman (1970) whose notion of a preparedness continuum was an attempt to reconcile some of the major problems that faced learning theory. It is from the context of this change that a new field has arisen, not to remove or replace behavioral psychology, but to extend it (see Terrace, 1984). This is the field of comparative cognition (Roitblat, Bever, & Terrace, 1984). The primary distinction between purely behavioral and cognitive theories is in the reference to internal representations by cognitive theories. The question of how representations might logically be developed within an organism leads quickly to consideration of perceptual processes (Shepard, 1984; Rilling, in press). Perception is the logical mediating process between objects and events in the real world and the internal representations of these objects and events. Thus, the most basic questions facing animal cognition today involve how animals perceive the world around them.

Stebbins (1990, p.23) in his review of the field of comparative psychology has concluded that it has not yet begun to handle internal representations. Indeed, the acceptance of the idea of animals having internal representations has taken considerable debate. But, methods of behavioral control which came out of Skinner's school of behaviorism have slowly become tools for uncovering the sensory and perceptual experiences of animals. Blough's (1958) method of finding sensory thresholds could be the first hint of this trend. Rilling and Nieworths' (1987) method of studying imagery is one current result of this trend. It seems that the formal systems of behavioral psychology which so adamantly rejected notions of internal mental events (e.g. Skinner, and Watson) have had their own methods turned upon themselves in a Gödelian proof of their incompleteness. While the cognitive revolution was in part a startle response to the incompleteness of the behavioral psychology of the forties and fifties, a more difficult and impressive result of the growing recognition from within animal research of the limitations of the behaviorist dogma has been the growth of the field of animal perception and cognition. Stebbins (1990) clearly points out the vast difference in the requirements for experimentally capturing perceptual as opposed to sensory processes. A perceptual process involves the organism's subjective interpretation of the stimulus. The experimenter cannot provide a definition of the stimulus through any procedural qualifications placed upon the subject's response. Stebbins (1990, p. 16) states that "It then remains for the experimenter to determine what elements, features, complexes, or aggregates of the stimulation introduced by the experimenter are controlling the subject's response." This study has been designed to investigate what complexes of features control the subject's responding in an object orientation discrimination task.

In order to do this, the stimulus must be adequately described by the experimenter in order to have some idea of what 'elements, features, complexes, or aggregates' might exist within the stimulus. Gibson (1979) has presented a novel approach to perception which involves describing stimulation in terms of its information, particularly higher order aspects which do not vary across circumstances which are termed invariants. Rilling (in press) has suggested that the notion of invariants within the stimulus array may be useful in expanding the notion of stimulus control into an ecologically valid theoretical concept for the study of animal perception and representation. Ecological validity refers to the degree to which a given phenomenon or theoretical account of a phenomenon is applicable to an organism living in its natural environment. Behavioral psychology has been charged with having poor ecological validity by ethologists as the Skinner box bears little resemblance to most natural habitats. Animal cognition and perception studies are concerned with developing empirical procedures which remain ecologically valid by applying these methods to problems which are common to a range of species (see P. M. Blough, 1991).

To the extent that different species share the same environment and face similar problems within that environment, we might expect to find similar solutions across species (see Olson's, 1991, discussion of spatial memory). This is bolstered by similarities in the underlying physiological systems which support the organisms' perception of the environment. This work is being done with pigeons, and the questions being raised regarding object recognition come, in part, from theories developed on the basis of studies of human object recognition. So, it might be asked how one could reasonably expect to be able to bridge the gap between human and pigeon. Aside from the obvious broad similarities in human and pigeon visual systems like the fact that each has a pair of visual organs called eyes, there are more meaningful similarities in the functioning of these systems.

Blough (1955) demonstrated that pigeons have a dark adaptation curve similar to humans using a procedure based on von Bekesy's method of ascending and descending limits. Pigeons have color vision similar to our own (Honig & Uricioli, 1981). Further, pigeons have edge detector ganglion cells (Maturana & Frenk,1963) which are similar to cells found in the visual systems of many other species. There are also differences like the existence of two independent fields of view (lateral and frontal) with the associated pair of foveal areas ('red field' and fovea) in each eye of the pigeon. Nye (1973) reviewed work on the visual acuity of the pigeons visual fields and concluded that the selection of the response measure is critical in obtaining appropriate results. The pigeon appears to be contra-prepared to associate stimuli presented in the lateral visual field with pecking responses, and prepared to associate laterally presented stimuli with locomotor responses. The frontal field is well designed for guiding the pecking response (Goodale, 1983). Further, the pigeon's frontal binocular field of view is only about 30 degrees wide (Martin & Young,1983; Bloch, Lemeignan, & Martinoya, 1987). It is this frontal binocular field which appears to be most similar to the human visual apparatus. Most research using visual materials with pigeons relies on the pecking response. This study will also use pecking as the response measure of choice.

Comparative perception and cognition is a rapidly growing area which relies on empirical methodology to obtain results about internal events in animals taking the subject's biological makeup into account. It has been demonstrated that these events may be investigated without invasive procedures designed to directly measure neural and/or neuro-chemical activity. This is much like the knowledge obtained by basic observation about color vision in humans prior to the existence of physiological methods of checking the optic system for three pigments in the retina, and finding opponent-process like neural activity. While internal events can be investigated without immediate resort to invasive procedures, the importance of verification and explanation of the physiological correlates of internal experience cannot be underestimated. The current approach is to use empirical procedures developed by behavioral psychology to guide the formation of formal theoretical models which can be rigorously tested.

Object Recognition

Until recently, the comparative approach has neglected the study of object perception and recognition. In Quinlan's (1991) review of two-dimensional shape recognition, the discussion of the animal-learning approach revolves around a few studies done in the 50's and 60's. These studies did not produce a cohesive theoretical approach to animal object recognition. But, Heinemann and Chase (1990) have recently developed a sophisticated template matching model of animal object recognition. However, there is also mounting evidence for the use of feature analytic processes in animal object recognition (Blough, in press; Rilling, DeMarse, & LaClaire, in preparation). Interestingly, the return to the question of object recognition by comparative psychology has been prompted by work done in another area of animal cognition involving a somewhat more cognitive act: Concept learning.

Concept Learning

Herrnstein (1984) described a variety of concept learning or categorization studies which led him to conclude that categorization could be conceptualized as perceptual object constancy. Cerella's (1990) work on pattern perception was clearly prompted in no small part by work in concept learning. Indeed, Wasserman (1991, MPA presentation) has essentially called for an increase in the amount of work that should be devoted towards object recognition theory and research within animal cognition labs. Wasserman presented results from a variety of concept learning experiments which have led him to conclude that the pigeons in these experiments are not actually learning a novel concept, but are uncovering some inherent aspect of the set of stimuli which is measurable through some stimulus similarity metric. The precise nature of this metric has not yet been uncovered, but it should be uncovered through studies of object and scene recognition.

An early experiment on natural concepts done by Herrnstein, Loveland, and Cable (1976) demonstrated that pigeons were able to correctly categorize novel instances of several different natural classes of stimuli. The basic procedure involves extended training in a discrimination procedure in which the positive stimuli contain examples of the stimulus class and the negative stimuli contain no examples of the stimulus class. Herrnstein, Loveland, and Cable (1976) used three classes of stimuli: Trees, water, and an individual person. Each set of stimuli for each class of stimuli consisted of over 1,500 unique pictures. About forty positive and forty negative pictures were presented on normal daily sessions. These pictures were randomly selected from the larger stimulus set of over 1,500 pictures for each stimulus class. Upon obtaining consistent discrimination of the positive and negative stimuli, the subjects were presented with sessions of entirely novel (previously unseen) pictures from the stimuli sets. The performance on these novel pictures was well above chance. The ability of the pigeon to categorize pictures which were selected based on a human notion of category membership leads to the question of what is it that allows the pigeon to perform this categorization task?

In order to provide a better picture of the process of categorization in the pigeon, Bhatt, Wasserman, Reynolds, and Knauss (1988) developed a more sophisticated procedure to investigate the phenomenon. This new procedure involved the use of multiple response keys and a multiple fixed ratio schedule of reinforcement. The pigeons are first trained to make a response on a viewing screen, then to respond on each of four corner keys. Using just ten slides to represent each of four categories, each corner key is assigned to a given category. The pigeon is reinforced for responding on the correct corner key after viewing any slide from the category that was assigned to that key. Incorrect responses resulted in correction trials in which the same picture continues to be presented until the pigeon makes the correct choice amongst the four keys. Only the response to the initial presentation of any given picture is counted in terms of the percent of correct categorization. Bhatt et. al. (1988) were able to demonstrate significant transfer to novel instances of the trained categories using this new procedure. Furthermore, Wasserman, Kiedinger, and Bhatt (1988) used this new procedure to test pigeons abilities to develop subcategories, and introduced a control for the possibility of pigeons being able to develop arbitrary categorization schemas. In the sub-categorization experiment, Wasserman et. al. (1988) presented 40 slides of each of two categories per session and required the pigeons to discriminate both the categories and subcategories by responding on one of four response keys as previously described. The subjects were able to learn both the categorization and sub-categorization tasks. However, more errors were made on the sub-categorization task than on the categorization task. The main importance of this finding is that the conceptual transfer found previously by Bhatt et. al. (1988) was probably not due to an inability to discriminate members within a category from one another. This suggests that pigeons are able to form a category based on some similarity amongst the members of the category while being able to distinguish between the members of the category which requires a flexible, yet detailed representational format. In the second experiment done by Wasserman et. al. (1988), the pigeons were trained using either human language categories or using pseudocategories generated using equal numbers of slides from each of the sets of slides used in the human language category training.

The basic procedure was similar to the procedure previously described. The main result was that the pigeons assigned to the pseudocategorization task did not achieve anywhere near the same level of ability to perform the four-key choice task as their human language categorization counterparts were. This indicates that while the pigeon is able to form categories which consist of distinguishable exemplars, these exemplars need to have some degree of visual similarity in order for categorization to achieve high levels of accuracy. Using non-similar exemplars, pigeons are less able to perform the categorization task which implies that the pigeon's memory is not as picture perfect as some have implied (Vaughn and Greene, 1984; Heinemann and Chase, 1990). In Wasserman et. al.'s (1988) second experiment, the pigeons were not able to memorize even a limited set of eighty unique slides. This finding argues against the task demands and against the photographic memory explanations of the performance of pigeons in categorization studies. It also points out the need for more research into the process of object recognition in pigeons which forms at least a part of the basis of the pigeon's conceptual capacities.

Cerella

Cerella (1990a) has developed an account of the pigeon's frontal visual field capacities which is closely linked to the perspective engendered by the motion of the pigeon's head as it pecks at stimuli. It is clearly a viewer-centered account. Viewer-centered approaches to object recognition emphasize the use of the perspective of the observer as the frame of reference for the representation of the object. Problems with, and alternatives to, viewer centered theories of object recognition will be discussed at greater length in subsequent sections. The reliance on head movement produced variability in viewpoint to generate an aggregate representation of the stimulus is very much like the sampling distribution used by Heinemann and Chase (1990) in their template matching model of object recognition which we will discuss later. Cerella's reasoning is closely linked to a series of studies (see Cerella, 1990a & 1990b) which he performed on the pigeons ability to perceive perspective transformations of two-dimensional stimuli. While I agree that head movements during pecking would produce variability in the perception of a stimulus on a response-to-response basis, and that this helps to account for Cerella's findings, there remains little reason to believe that this variability bears a direct relationship with the development of an aggregate representation of the stimulus. Indeed, as will be revealed by a careful examination of Cerella's methods and results, the degree of variability introduced by the pigeon's pecking movements is directly related to an inability to readily distinguish between different stimuli which indicates a failure to adequately represent these stimuli as different from one another.

Cerella (1990a, p. 144) clearly indicates that probe trials in his first experiment were "summarily terminated" at the end of a ten second interval. This is readily seen as an extinction condition by anyone with even a passing knowledge of operant theory. Yet, Cerella (1990a, p. 142, my emphasis) expects to find "a continued tendency to respond to a probe" as evidence for perspective invariance. A generalization gradient with an increasingly steep slope over time is what would be predicted on the basis of the schedule assuming the pigeon could discriminate between the probe and the positive stimuli. Indeed, this is exactly what Cerella (1990a) obtained with most of the probes. The exceptions being right and left shifts in the location of the positive stimuli to which the pigeons continued to respond at a high rate. These shifts, however, were quite small (approximately 1.6mm) and only changed the location, not the arrangement of features, of the positive stimulus relative to the frame of the display window which was 30mm wide. It is quite likely that the pigeons did not attend to stimulus location as this was not incorporated into the original discrimination whereas stimulus configuration was. In his second experiment (Cerella, 1990a), the procedure was identical except that each probe was presented four times per session over four sessions or 16 times (except in two cases which received one extra session for each type of probe). In this experiment the stimuli were simple geometric forms. The positive stimulus was a single prototype (either a chevron-like figure or a trapezoid-like figure) and gross distortions generated by randomly displacing vertices were the negatives. Moderate distortions, either systematic (rotations, enlargements/reductions, and translations) or random, served as the probes. Once again, the discrimination task required the pigeons to make a discrimination based on stimulus configuration and not location or size. Thus, the deck is already stacked against probe transformations which alter the stimulus configuration as exemplified by the Z-rotation probes which have a horizontal line on the bottom at the lowest distortion level, but soon have a diagonal line on the bottom at higher levels of distortion. Furthermore, Cerella's procedure is still not a steady state procedure and can only determine the degree of difficulty in making a discrimination between a probe and the positive stimulus. This, ultimately, means that Cerella's procedure does not provide us with a basis for indicating the degree to which pigeons are able to recognize appropriate transformations of a two-dimensional stimulus as being transformations of that stimulus. The information obtained from the initial exposure to a given probe type may provide a more accurate representation of the pigeons abilities prior to the learning effects produced by presenting the probes using an extinction contingency, but the problem with the initial training requiring the discrimination to be made on the basis of stimulus configuration remains. Unfortunately, Cerella does not present any information regarding the initial trials of probe testing.

In conclusion, Cerella's (1990a) account of pigeon visual recognition abilities as being limited and based entirely on viewer-centered distortions of the object is not based on an appropriate set of experimental evidence. The flaws in Cerella's work involve his choice of stimuli for discrimination training, and his use of prolonged exposure to probes presented under conditions of extinction. While the probe trials being presented under extinction conditions can be controlled for by looking at the resulting extinction curve across sessions, the initial discriminations which were used did not provide a fair basis for comparing the transformations which Cerella used. The discriminations which Cerella used were biased against changes in the configuration of the features of the stimulus relative to the canonical orientation, but not location or size. The resulting decrement in responding to the probes in which the canonical orientation has been altered cannot be attributed to the pigeon relying on a strict template matching approach to object recognition which would reject such probes.

Heinemann & Chase

A sophisticated template theory of object recognition for animals has been put forth by Heinemann and Chase (1990). This theory surpasses the limitations of traditional template models by allowing mental transformations of templates. The templates are actually complete descriptions of objects and scenes which utilize all possible features. For example, a black outline of a square one point (or pixel) in width on a white field would be represented by a template which consisted of an exhaustive listing of every black and every white point in the scene. The primary distinction between a feature analytic theory and Heinemann and Chases' template model is that features are not analyzed, but are used directly and completely in the ultimate high-level representation or template proposed by Heinemann and Chase. The only process intervening between the stimulus and its internal representation is a statistical sampling process which represents the movement of the animal's focal attention across the display.

Template theories have oft been criticized for requiring too much memory space to be practical as a result of needing too many templates to effectively recognize the diverse range of objects that people are known to be able to recognize. Chase and Heinemann (1989) and Heinemann and Chase (1990) describe results from concept learning types of experiments like Vaughn and Greene (1984), and Vaughn and Greene (1983) as providing evidence that the pigeon's memory capacity is not a limiting factor for their theory of object recognition. These experiments tested pigeon's memory capacity by training the pigeons to discriminate between unique sets of pictures which did not have any cohesive visual features or distinguishing forms. The results indicate that the rote memory capacity of pigeons was not taxed with a set of more than 300 unique pictures. Heinemann and Chase (1990) suggest that evidence of an impressive capacity for remembering unique pictures gives them a sound basis for developing their memory-intensive template model. Unfortunately, this evidence does not speak to the underlying process or method whereby the ability to remember a vast number of unique images has been conferred upon the pigeon. Indeed, an alternate hypothesis regarding the underlying means utilized by the pigeon to perform this sort of feat exists which rejects the use of templates. This hypothesis is that the pigeons in concept learning experiments are able to compress their representations of complex scenes via analysis of the features in the scene. This method of compressing the ultimate representation, probably akin to 'chunking', uses intermediate features like segments and vertices and their structural relationships to produce a compact ultimate representation.

Heinemann and Chase (1990) are wary of 'covert' normalization processes for dealing with the ability to recognize objects in novel orientations, and from novel perspectives. They suggest that overt normalization processes related to head movements are more appropriate and less likely to be challengeable. In their focus on these overt normalization processes, they utilized information about pigeon head movements and ran a simulation of Cerella's (1990a) second experiment using their model. The model matched Cerella's data quite well. Unfortunately, Cerella's results are in question at this point as previously reviewed. Thus, the utility of their model cannot be judged appropriately on the basis of this simulation.

Another major limitation of Heinemann and Chases' model is that it is inherently and intractably viewer-centered. This criticism refers to the frame of reference utilized in the representational format for visuo-spatial information. The viewer-centered frame of reference only allows for the representation of an object from the viewpoint of the observer. The main criticism of the use of viewer-centered frames of reference is that novel perspective views of a familiar object would be unrecognizable as the stored perspective view most likely afforded a considerably different image from the new input. The frame of reference which has been proposed to allow the rapid recognition of familiar objects from novel perspectives is termed the object-centered frame of reference. The representational co-ordinates of this frame of reference are centered on the object instead of the viewer. In Heinemann and Chases' model, there is no provision for developing or altering their ultimate representation such that it becomes object-centered. The sampling process which generates the representation is based entirely on the observer's unique perspective of the scene. At no point is there a good means for the abstraction of the primary axis of elongation of a given object (a requirement for the generation of an object centered representation as described by Marr and Nishihara, 1978) or the generation of a single unique representation of the object without a bias of observer perspective.

Blough

Blough has investigated pigeon object perception and recognition for quite some time, and has used more than one methodological approach (Blough, 1977; Blough, 1979; Blough, 1985; Blough, in press). Blough (1977) pioneered a visual search task for pigeons. Reaction time as opposed to response rate is the dependent measure of choice in visual search tasks. Visual search is a task in which a target stimulus is presented amidst an array of distractors. The subject is required to find the target. Common variables in visual search experiments are the array size and the similarity of the target and distractor. Blough (1979) found visual search effects similar to those documented for humans such as increasing search time for increased numbers of distractors and for distractors which were judged to be more similar to the target form. Blough (1985) has also investigated pigeons abilities to discriminate amongst letters and amongst random dot patterns. Blough (1985) used a three key discrimination procedure in which one letter served as a positive stimulus and another served as a negative stimulus during each trial. Every letter served as the positive and negative stimulus at some point during this experiment. Blough analyzed the error data to generate confusion matrices amongst the letters of the alphabet. He was able to identify clusters of letters which were similar in physical features which the pigeons commonly confused with each other. Blough's (1985) discussion of this data does not strongly favor feature analysis models over template matching models, but does tend to lean in the direction of feature analysis models. Blough does point out that the features discovered using a particular set of stimuli may not accurately represent universal features due to hierarchical processing in feature models (cf. Palmer, 1977).

Blough (in press) is more strongly favorable to the notion of a feature model for object recognition in pigeons. Blough presented results from carefully constructed visual search experiments which seem to reject template matching models. In one such experiment, three stimuli were constructed such that when any pair of the stimuli was superimposed, there was an equal amount of overlap which would produce equal difficulty in distinguishing between all possible pairs assuming a template matching process was being used. The differences in relationships between the segments of the different stimuli provides features which a feature analytic process might be able to use to differentiate between the stimuli. The results indicated that search was not performed with equal facility for all target-distractor pairings. While this supports the notion of a hierarchical feature process being utilized, the higher level features which were assumed to be being used were not identified. Further work using a larger set of stimuli composed of vertical and horizontal line segments resulted in the identification of symmetry about the vertical axis as a possible high level feature for pigeons. Another high level feature which was identified in another experiment (Blough, in press) was the 'absence of a gap'.

In conclusion, Blough has done a variety of thought provoking experiments which seem to support a feature analytic process as the underlying mechanism of object recognition for pigeons. While the support for a feature analytic process is growing, Blough (in press) still has not presented a complete model of this process. Indeed, Blough has not been willing to set forth any definitive set of elementary features, but has restricted his theorization to the specific sets of stimuli which he has used in his work. This is probably wise at this time as it avoids making claims which go beyond the base of knowledge which has been thus far accumulated. However, the need for delineating a more complete, specific and detailed model of pigeon feature analysis is clear.

Rilling and LaClaire

Rilling, DeMarse, & LaClaire (in preparation) have recently completed a pair of studies of simple object recognition. These studies used simple line drawings of two- and three-dimensional figures. A discrimination procedure was employed in which a figure of a cube and a figure of a truncated pyramid served as the S+ and the S-, respectively. After the pigeons had demonstrated a significant difference in their responding to the two stimuli, a generalization test was run using stimuli having different amounts of contour deleted either at the vertices or at the midsegments of the figures. The pigeons responded significantly more to the condition in which the midsegments remained than the condition in which the vertices remained. This implies that the pigeon sees a set of midsegments of an object as being more like the object than a set of vertices. Midsegments are more heavily weighted features for object recognition than vertices for pigeons. Wasserman et. al.

(1990) have obtained an analogous result using more complex figures with a more complex procedure with pigeons.

Having established a fair amount of evidence supporting the use of features by pigeons in the process of object recognition previously (Rilling, DeMarse, & LaClaire, in preparation; see also Blough, in press), the next question of importance is: How are these features organized during object identification? This question has been approached from diametrically opposed positions: The wholistic gestalt school and the atomistic structuralist or S-R school. It has been recognized that neither position has a corner on the truth in the market of object recognition processes. The suggestion that some sort of interaction between these approaches is closer to the truth is evident in Vitz and Todds' (1971) and Palmer's (1977) models of perception of figures. Both models have suggested that there may be a hierarchical structural organization of elements. The hierarchical nature of these models surpasses strict atomistic positions by allowing for intermediate representations comprised of more than one feature or element. These intermediate representations are in turn combined to form higher level representations and eventually the figure or object is represented by its own unique representation. Vitz and Todds' (1971) model does not provide intuitive intermediate representations, but rather abstract representations of symmetry and complexity.

Palmer's model utilizes more intuitive intermediate levels of representation which could be considered to correspond to different parts of a figure. There are many possible ways to organize the features of a given object into parts. How the features are organized into parts will depend on relations between the features. Some parts are, according to Palmer, 'better' than other parts based on gestalt laws. A 'better' part in Palmer's theory is one which has a greater probability of being described by the perceptual system as a unitary structural unit having its own level of analysis. Palmer (1977, p. 443) defines structural units as "elements of perceptual representation that can be processed as a single entity, regardless of their internal complexity, at a global level of analysis."

Palmer

Palmer's (1977) research indicates that the gestalt law of proximity accounts for most of the differences in the 'goodness' of parts. He presented an algebraic model for determining the goodness of a part given an object. The model was developed for empirical and not theoretical purposes. Unfortunately, the model is most useful with proximity as the primary dimension according to Palmer's empirical results. Proximity is simply denoted as the euclidean distance between the midpoints of a pair of segments. Each dimension within the model is weighted. The proximity dimension requires a weight of -1. The scale value denoting the relationship between any pair of segments in an object along the proximity dimension is then calculated by multiplying the distance between those features by -1. This is labeled as $R(i,j)$ in Palmer's algebraic model with i and j representing two non-identical segments of a figure.

In order to determine the goodness of a part of a given figure, first, the scale value of the relationship between a segment within the part and each segment not within the part is subtracted from the scale value of the relationship between that segment and each other segment within the part. This function is computed for all of the segments of the given part and the resulting values are summed. The resulting quantity is then divided by the quantity of the number of segments within the part times the quantity of the number of segments within the part minus one times the quantity of the total number of segments minus the number of segments in the part. The equation for this calculation which represents Palmer's model can be expressed as $G(P|F)=\{(f-p)*\Sigma i=1->p\Sigma j=1->p,j<>p\ R(i,j) - (p-1)*\Sigma i=1->p\Sigma k=p+1->f\ R(i,k)\}/p(p-1)(f-p)$. This equation is for the Goodness (G) of a specified part (P) given a figure (F) where f is the number of features in the object, p is the number of features in the specified part, i and j are features shared by the part, and k is a feature not present in the part. Thus, the R(i,j) values represent the within part scale value, and the R(i,k) values represent the between part values. The larger the goodness rating is, the better the part is organized.

The reason for using a weighting of negative one for the proximity dimension should now be clear. The model calls for the subtraction of the presumably large(r) distances between segments not contained within the same part and the presumably small(er) distances between segments contained by the same part given that the part's segments have close proximity to one another. This would result in small (even negative) goodness ratings for parts composed of features which are close together. However, by weighting the scale values of the proximity relations between features by a negative one, the within part values are subtracted from the between part values resulting in higher goodness ratings for parts composed of segments having high proximity than the goodness ratings of parts which are composed of segments which are not in close proximity to one another.

Experiment One

Two figures differing only in orientation were generated for the purpose of the present work. This difference provides two important controls for this work. Firstly, the positive and negative stimuli may be broken up into identical sets of parts. Secondly, this discrimination does not generate an a priori bias along the proximity dimension. These figures were decomposed into two triplets of parts -- one triplet having a higher average goodness rating than the other (High proximity parts X=0.65, Low proximity parts X=0.24). The pigeons were first trained on a simple discrimination between the two figures. After attaining a high discrimination ratio under steady state conditions in which the subject was not always reinforced for responding to the positive stimulus, unreinforced probe trials were presented to the pigeon. These probes consisted of either high proximity or low proximity part triplets which were separated by a small distance form one another (0.2 cm) or a large distance (0.5cm). Each figure was composed of nine segments. Each part triplet contained one part with four segments, one part with three segments, and one part with two segments. If the proximity dimension is important for the pigeon, then a decrement in responding should be seen to the low proximity part triplets relative to the high proximity triplets during the positive generalization test. Furthermore, there should be a decrement in responding to the large separation part triplets relative to the small separation part triplets during the positive generalization test. Template matching theories would predict that there would be no difference in the rates of responding along the proximity dimension, but would also predict a reduction in responding to the large separation part triplets during the positive generalization test.

Method

Subjects

Seven naive White Carneaux pigeons were observed performing discrimination and generalization tasks. These pigeons were previously trained to respond to an electromechanical key on a fixed ratio schedule of reinforcement and to respond to a black dot presented on a secondary computer monitor with a touch sensitive screen using a fixed interval schedule of reinforcement. None of the pigeons had prior experience with discrimination or generalization procedures. None of the pigeons had any prior experience with the stimuli used in this experiment or stimuli that were similar to those used herein. The pigeons were maintained within 20g above their 80% of free feeding weights.

Apparatus

The apparatus used here has been described in Rilling and LaClaire (1989). Stimuli were presented on a 30 cm black and white monitor controlled by a Macintosh Plus computer. Responses were collected through the use of a touch sensitive frame (Carrol Touch Technologies) mounted on the monitor and interfaced with the Macintosh Plus computer via the parallel communications port on the computer. Reinforcements were provided and houselights turned on and off by a Benchtop Instrument (MetaResearch Corp.) which maintained an interface with the Macintosh Plus via the serial port.

The experiments were conducted using software developed at Michigan State University by T. L. LaClaire in the Rascal programming language which was developed at Reed College. The program used is titled "PRII.05b" which stands for Psychology Research -- Version II.05b. A listing of this program and instructions for its use (instructions written by Miss. D. Vreevn) may be found in appendix A, and questions regarding it should be forwarded to the author at the Department of Psychology at Eastern Illinois University in Charleston Illinois. This program provides an easy interface for the design and performance of simple discrimination and generalization experiments using the hardware previously described. It uses 'pict' files for the storage and presentation of stimuli which may be generated by a number of standard drawing packages like MacDraw (tm).

Stimuli

The stimuli were generated using MacDraw (tm). The stimuli used in the training phase were two different orientations of the same figure. The figure used was a two-dimensional representation of a rectangular cube with hidden lines erased. Three faces of the rectangular cube were present in each view of the stimulus. One face was a square, and the other two faces were parallelograms. These figures were constructed from nine segments of varying lengths. Probe stimuli were generated by breaking the figure into three sets of segments called parts. These parts were judged on the basis of the relative proximity of the segments within and between the parts. One set of parts had high proximity as indicated by a high goodness rating, and the other set of parts had low proximity as indicated by a low goodness rating. Probe stimuli consisted of a complete set of parts (either high or low proximity) which were separated by either 2mm (small separation) or 4mm (large separation). All stimuli and ratings are presented in figure 1. The definitions and equations required for the calculation of the goodness ratings of the parts and examples of the application of these equations to these stimuli are provided in appendix B.

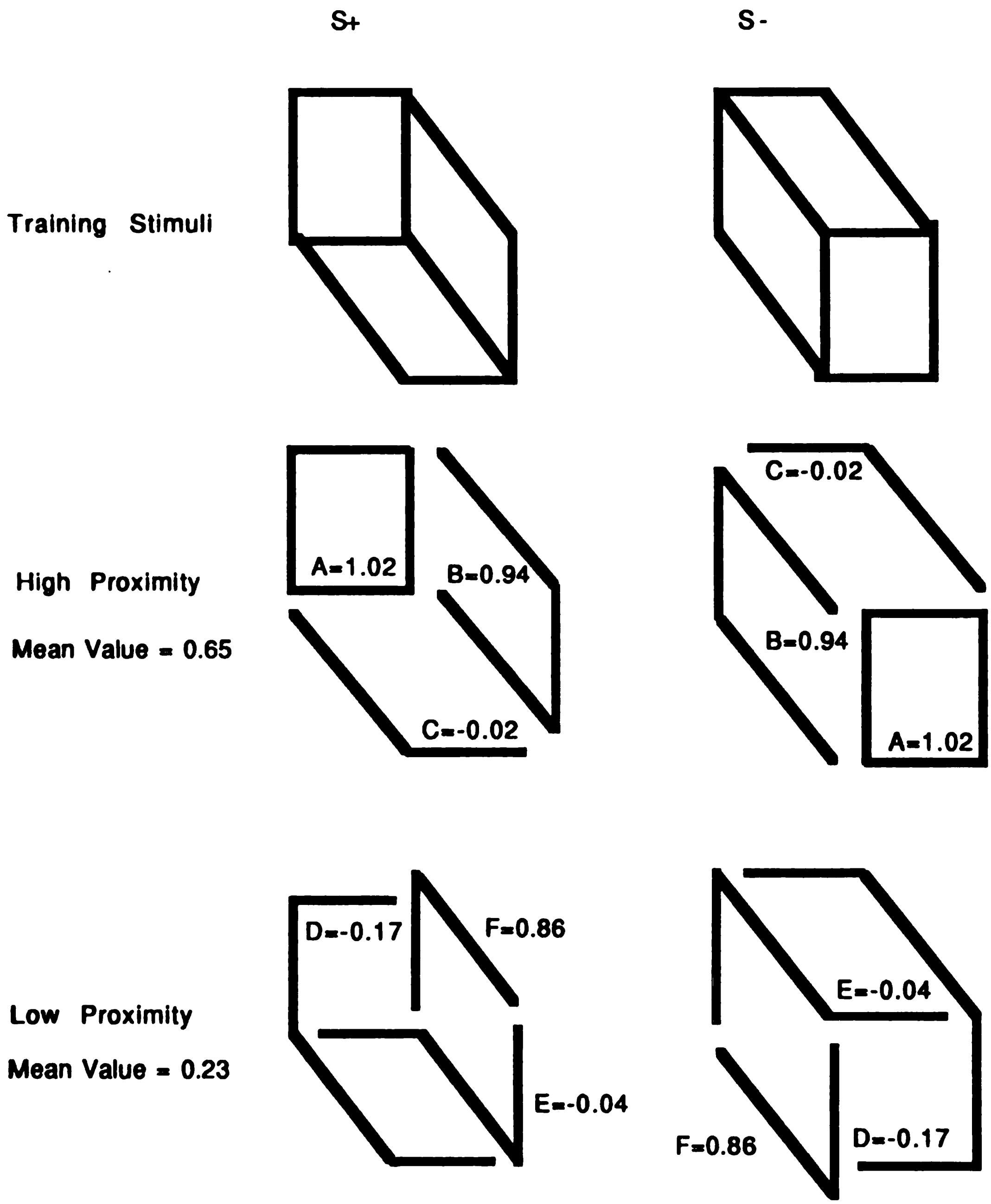


Figure 1: Stimuli used in experiment one

Procedure

Discrimination training began with the presentation of the positive and negative stimuli in randomly arranged blocks of ten trials. Each kind of stimulus was presented thirty times per session for a total of sixty trials per session during the initial training phase. Each stimulus was presented for approximately 10s. Trial onset was signaled by turning on the houselight in the chamber. The houselight was turned off at the end of each trial. The positive stimuli were presented on a FI 10s schedule in which the stimulus presentation was terminated by the first response after 10s had passed. This response produced a reinforcement of access to mixed grain for 5s. The negative stimuli were presented for ten seconds and then the screen was cleared and a trial onset delay was initiated dependent on the number of responses to the negative stimulus. This delay period was increased by 2s for every response if there were more than three responses. Thus, a negative trial in which there were two responses would produce no time-out period, but a negative trial in which there were five responses would produce a time-out period of ten seconds. Once a pigeon's discrimination ratio had risen above 0.80 on two consecutive sessions, the block size was decreased. Block sizes were decreased from ten to five to three to one. Upon attaining a discrimination ratio of greater than 0.80 on two consecutive days with a block size of one (positive and negative trials completely randomized), five unreinforced trials of the positive stimulus were introduced. A total of sixty-five trials per session were given during this phase of training. This produces a resistance to extinction of the response to trials in which a stimulus similar to the S+ is presented but not reinforced which provides us with a steady state testing situation. Despite this procedure, the responding of the subjects to probe stimuli has been observed to decrease (see Rilling and LaClaire, in preparation). Sessions of training with the added unreinforced S+ trials lasted until the stability criterion of two consecutive trials with a discrimination ratio of greater than 0.80 was met.

At this point, generalization testing was begun. Each session of generalization testing consisted of the previously described trial types, plus eight novel probes. These probes were presented under conditions of extinction without added time-out for responding during these trials. There were two trials of each probe type per session resulting in a total of eighty-one trials per session during generalization testing. The eight novel probe types were generated using the eight combinations of the following three pairs of variables: Positive vs. negative stimulus, high vs. low proximity, and large vs. small separation. Five trials of generalization testing were run, but only the first three were analyzed due to the reduction in responding to the probes observed over time.

Results

The pigeons rapidly acquired the initial discrimination reaching criterion performance at the lowest block size with S+ Extinction trials in an average of 28.2 sessions, ranging from 19 sessions to 38 sessions. The most and second most variability in the number of sessions to reach a criterion for a given block size was found for block sizes of ten and five, respectively. It took an average of 13.2 sessions to reach the criterion performance of a discrimination ratio for two successive sessions greater than 0.80 with a block size of ten. It took an average of 8.7 sessions to reach criterion with a block size of five. In the remaining block sizes (three, one, and one with S+ Extinction trials), the average number of sessions was less than 3 which indicates that the pigeons had learned the discrimination by the time they had reached the criterion with a block size of five which occurred within an average of 21.8 sessions. Figure 2 shows the stimulus generalization gradients. During the positive stimulus generalization test, the mean rate of

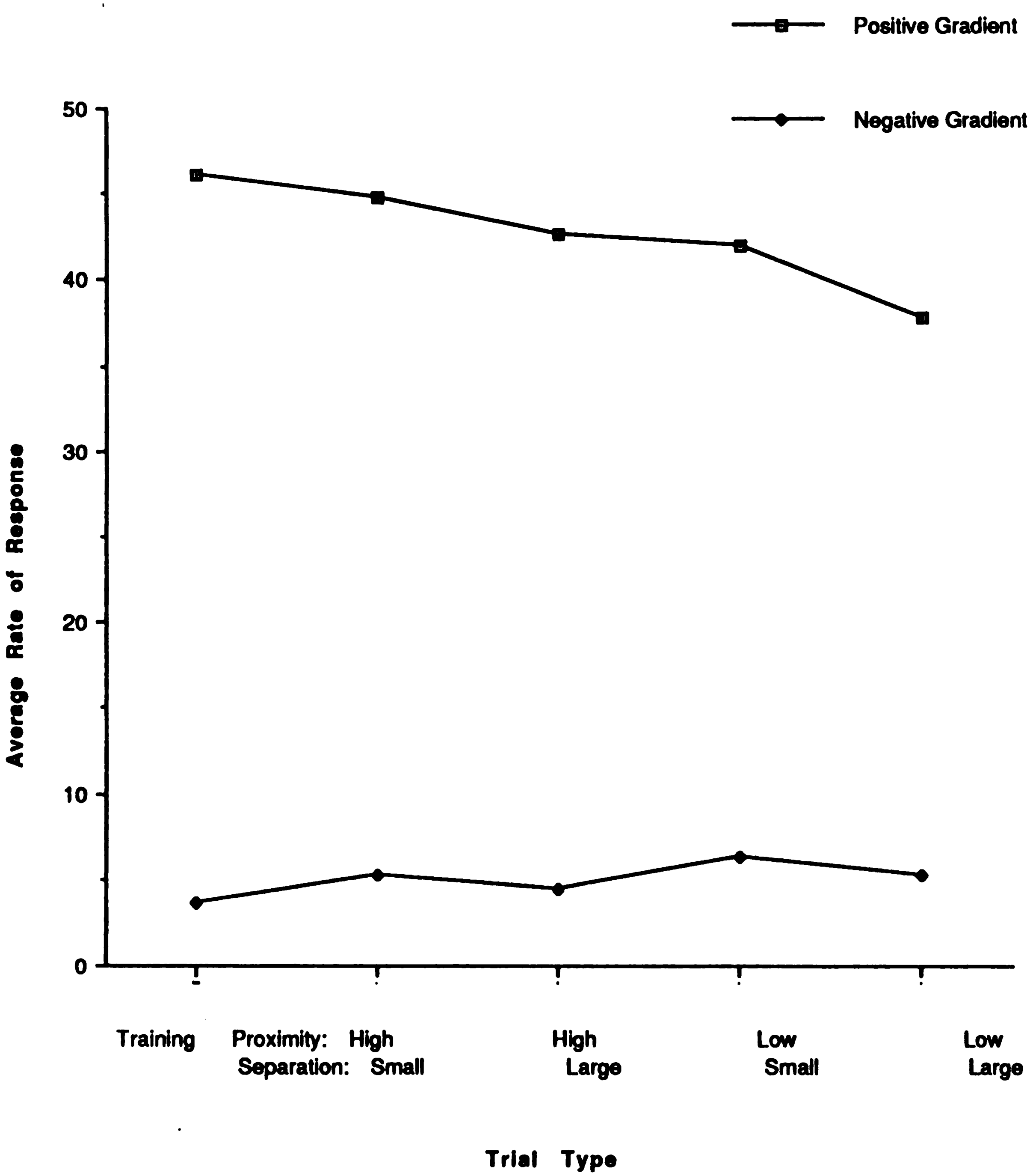


Figure 2: Generalization gradients

responding to the high proximity, small separation probes was 44.8 responses per session. The mean rate of responding to the low proximity, small separation probes was 41.9 responses per session. The mean rate of responding to the high proximity, large separation probes was 42.7 responses per session. The mean rate of responding to the low proximity, large separation probes was 37.8 responses per session. It can be seen that the rates of responding declined across the high vs. low proximity conditions, and across the small vs. large separation conditions in the positive generalization test. It can be seen that the rates of responding during the negative stimulus generalization test remained under 6 responses per session for all negative probes. The data from the negative generalization test will not be considered any further as there appears to be an obvious floor effect. The only interesting facet of this is noting that the discrimination between the positive and negative stimuli was not degraded under the probe conditions in which the training stimuli were altered. The rates of responding during testing for the individual subjects across all conditions may be found in appendix C.

A within subjects 2 X 2 analysis of variance with three repeated measures was performed on the two levels of proximity, and the two amounts of separation for the first three sessions of probe testing. No effects were significant: Proximity ($F(2,12)=2.36$, $p>0.1$), separation ($F(1,6)=1.27$, $p>0.1$), trials ($F(2,12)<1.0$), proximity by separation ($F(1,6)<1.0$), proximity by trial ($F(2,12)<1.0$), separation by trial ($F(2,12)=1.79$, $p>0.1$), and proximity by separation by trial ($F(2,12)<1.0$).

A within subjects one way analysis of variance on the rates of responding to the positive stimulus, and the four types of positive probe trials on the first day of probe testing was performed. No significant effect was found ($F(4,24)=2.55$, $p>0.05$) for type of trial, although this analysis did approach significance ($p=0.065$). Subsequent linear contrasts also failed to find any significant differences. The contrast between responding to the positive stimulus and to all of the probes was not significant ($F_{contrast}(1, 24)=4.39$, a priori $p<0.05$, post hoc (Scheffe's test), $p>0.05$). The contrast between the two levels of proximity within the probe conditions was not significant ($F_{contrast}(1, 24)=2.09$, $p>0.05$). The contrast between the positive stimulus and the probes having high proximity was not significant ($F(1, 24)=1.75$, $p>0.05$). The contrast between the positive stimulus and the probes having low proximity was not significant ($F(1,24)=7.31$, $p<0.05$, post hoc (Scheffe's test), $p>0.05$). As indicated, two of the contrasts would have been significant had they been planned a priori contrasts. Differences approaching significance exist between the positive stimulus and all of the probe conditions and also between the positive stimulus and the low proximity probe conditions.

A closer examinatin of the data indicated that one subject was responding approximately between two-thirds and three-quarters as much as the rest of the subjects to the positive stimulus. This subject was not run under my direct supervision, however its lower rate of responding to the positive stimulus is cause for some concern about its overall performance. Analysis of the data without this subject does result in significant differences being detected.

The main effect for level of proximity was significant ($F(1,5) = 7.42$, $p<=0.05$). No other effect or interaction was significant: Trials ($F(2,10)=1.01$, $p>0.1$), Separation ($F(1,5)<1.0$), Trial X Proximity ($F(2,10)<1.0$), Trial X Separation $F(2,10)=2.24$, $p>0.1$), Proximity X Separation ($F(1,5)<1.0$), and Trial X Proximity X Separation ($F(2,10)<1.0$).

Response latencies to the different probe types were also recorded and analyzed. Figure 3 presents the median response latency to each type of probe trial. As can be seen, there are only slight differences in median response latencies. A Friedman analysis of variance by ranks was used as latency data frequently does not conform to assumptions of normality required for performing standard analysis of variance statistical methods. This analysis was performed on the latency to respond on the first probe trial for each type of probe across all subjects. The analysis indicated that there were no significant differences in response latencies to the different stimuli ($\underline{X}_r^2 = 5.25$,

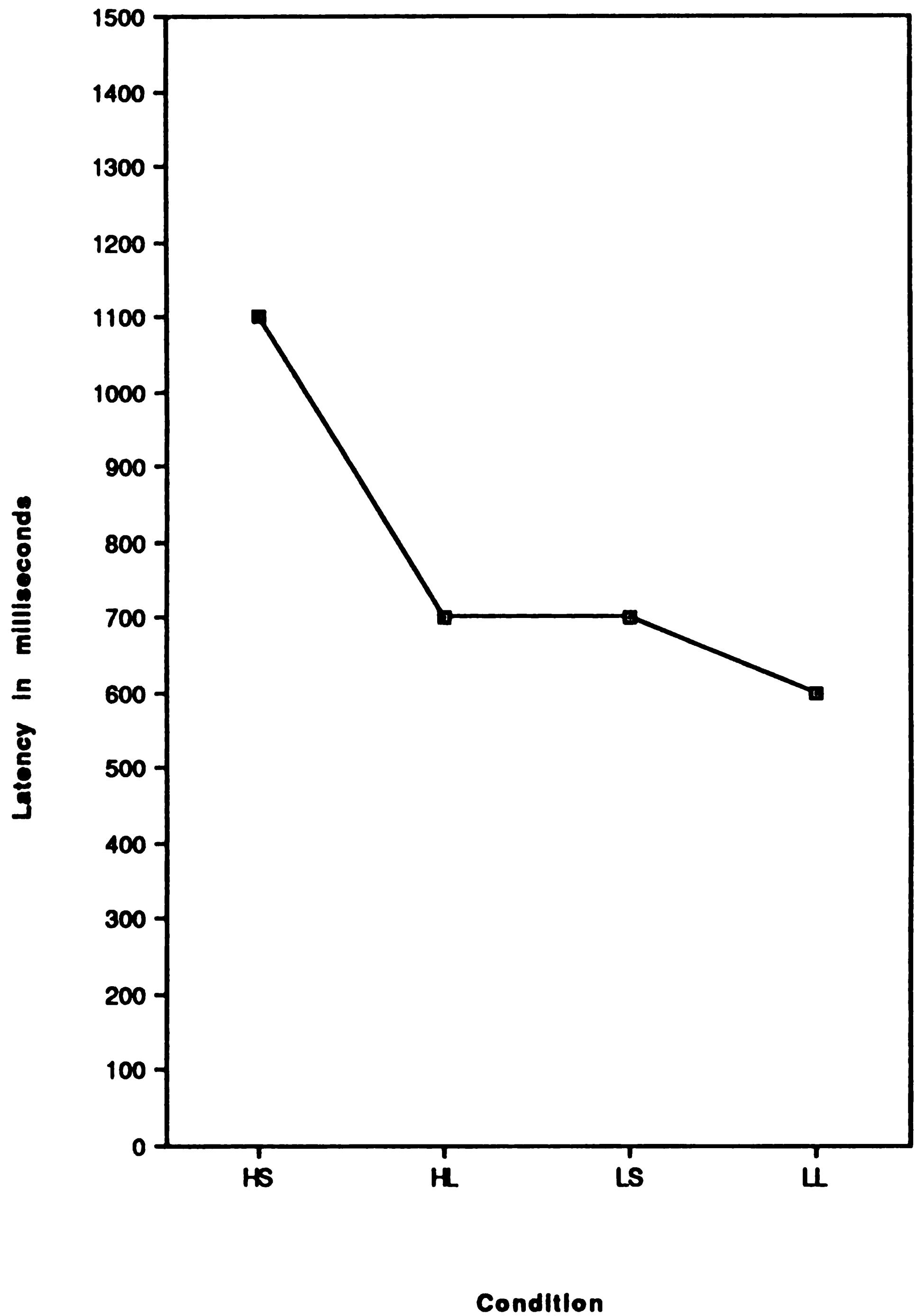


Figure 3: Median response latencies

$p>0.05$). The response latency data, and the response time distribution data are provided in appendix C for the interested reader.

Experiment Two

The results of the first experiment conformed fairly well to the expectation that pigeons use features to organize features of objects into hierarchical parts. The pigeons responded more to the group of parts which had high proximity values. There was no effect of the amount of separation on the amount of responding which may just indicate that the difference between the amounts of separation were not sufficient to produce any generalization decrement that would denote a loss of the gestalt of the complete form. Unfortunately, this experiment was not able to conclusively implicate proximity as the organizational principle being used.

The second experiment was designed to account for different possible organizational principles which may be controlling the subject's responding. In the initial experiment, the results indicate that some organizational principle appears to be being used by the pigeons to hierarchically group features into parts of an object. The principle of organization which held our interest was proximity. However, the principle of closure could have accounted for the results as well since the high proximity stimulus had the only part which was closed. So, for this experiment, a new high proximity stimulus was constructed which did not have any closed parts. The probe stimuli used in this experiment are presented in figure 4.

It should be noted that in this experiment the stimuli were single parts of the object which represent a major reduction in the amount of total contour of the training objects presented during any given probe trial. The rationale for using single parts was to refine and restrict the comparison to the within part proximity rating without additional higher level between part relations having any part in the results. The calculation of individual part proximity ratings proceeded via the same methods used in experiment one.

Method

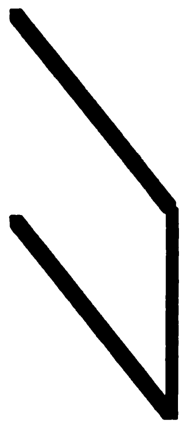
Subjects

The same pigeons were used in this experiment as in the previous experiment. They were maintained in the same manner as in the initial experiment.

Apparatus

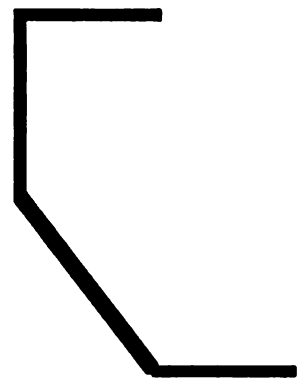
The same equipment was used in this experiment as in the previous experiment. The computer program PRII.05b was also used to run this experiment.

High Proximity | Low Proximity



Part B

0.94



Part D

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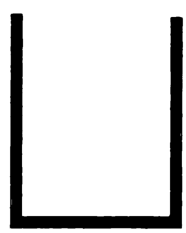

Part G

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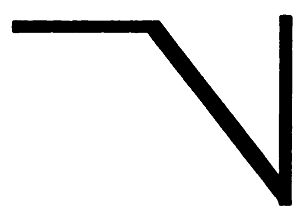

Part E

0.04

Figure 4: Stimuli used in experiment two

Procedure

The procedure was identical to the initial experiment, except that the subjects were given ten sessions of re-training on the initial discrimination task during which the number of S+ Extinction trials were increased from five to ten per session. The subjects were then probe tested for five sessions using the probe stimuli presented in figure 4 with their associated proximity rating values. Trial durations and contingencies were identical to those in experiment one for S+, S-, S+ Ext, and Probe trial types. Trial order was also randomly determined for each session as it was in the previous experiment. However, only a positive stimulus generalization gradient was sought. No individual parts which corresponded to the negative orientation were used in probe testing.

Results

The initial discrimination ratios did not fall below 0.80 despite the change in the relative frequency of unreinforced positive trials. The response rate for the positive stimulus remained high throughout, averaging between 21 pecks per trial for the least responsive subject to 31 pecks per trial for the most responsive bird. The rates of responding to probe trials represented very large decrements in responding relative to the rates of responding to the positive stimulus with two pigeons being practically totally non-responsive. The effects of this near total lack of responding to probe trials is evident in figure 5 which presents the mean rates of responding to the positive stimulus, and each part probe. The complete response rate data may be found in appendix D.

A within subjects 4 way analysis of variance with three repeated measures was performed on the four parts for the first three sessions of probe testing. No significant main effects or interaction effects were found. The main effect of part was not significant ($F(15,3)=1.96$, $p>.1$). There were no significant effects across trials ($F(10,2)=1.52$, $p>.1$). The interaction between parts and trials was not significant ($F(30,6)=2.03$, $p>.05$).

The response time data was not analyzed as this data was not helpful in experiment one where there was a significant amount of responding to the probe trials, and significant differences in rates of responding to different conditions. To say that the response time data is not likely to provide any insights in this instance is supported by the size of the decrement of responding across all conditions. However, for the interested reader, the response time data is provided in appendix D.

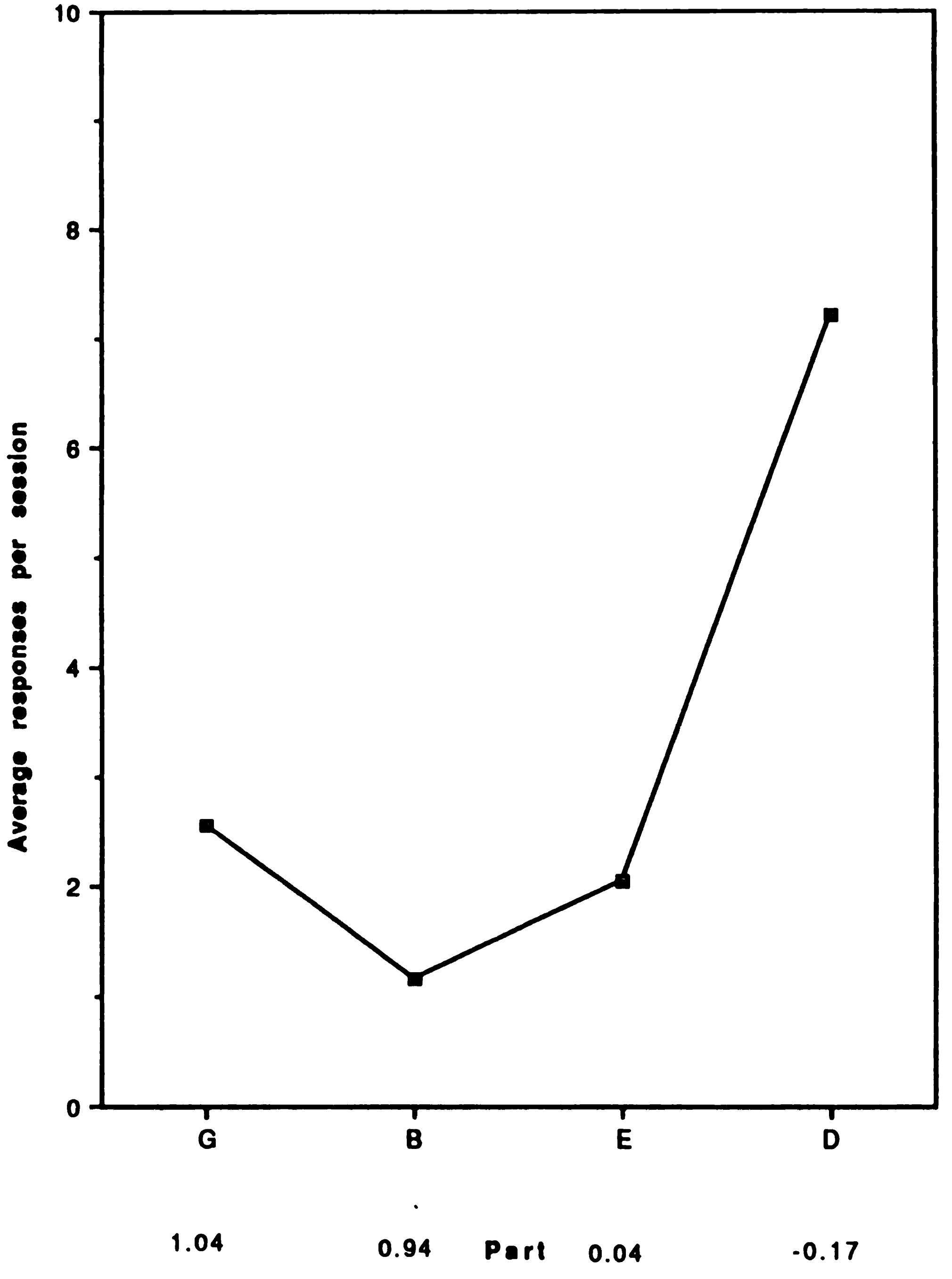

Figure 5: Mean rates of responding to parts

Discussion

The primary conclusion which can be drawn from this experiment is that pigeons' perceptual systems may use some principle of perceptual organization, either proximity or closure, to group features of objects into parts. This conclusion remains tentative as there were no significant differences in response rate to probe stimuli which consisted of parts with high proximity values compared with the rate of responding to parts having lower proximity values during the positive generalization test. The data appear to be in the correct direction, however the methods used may not have been sensitive enough to detect a difference in a higher perceptual process. Furthermore, the power of the test remained relatively low -- a larger sample size would have been more desirable.

A template matching theory would not predict this result, and cannot readily account for it without incorporating feature analytic processes in the service of constructing the ultimate high level representation to be used as a template. There were no a priori biases created by the selection of the initial stimuli which were used in the discrimination training as these stimuli were not distinguishable on the basis of the proximity of the features of which they were composed. The testing was performed under steady state conditions as there was no significant effect across trials despite the probe stimuli being presented under conditions of extinction. Thus, one means of grouping features which has been found to be significant in human perception of line drawings (Palmer, 1977) may also be used by pigeons.

This experiment is somewhat similar to Palmer's (1977) third experiment which was a part verification task. This task involved asking a subject to make a yes/no judgement about a part being present in a given figure. Parts which had high, medium, and low goodness based on the proximity dimension were tested. Palmer (1977) found that the reaction times were significantly faster for parts with higher proximity ratings. This led Palmer to reject template matching theories. Palmer also indicated that this result could be dealt with by the use of a hierarchical perceptual processing model in which features were grouped into structural units which could be combined to generate higher level structural units. Recognition in this process would occur in a top down fashion from the highest level structural unit to lower level structural units. Parts with high proximity will more likely be coded as higher level structural units than parts with lower proximity ratings.

At this point in time, there is a growing body of evidence that the visual perceptual systems of pigeons use features as a means of developing high level representations of objects. This evidence comes from studies by Rilling, DeMarse, and LaClaire (in press), Blough (in press), and by Wasserman, DeVolder, van Hamme, and Biederman (1990). The Rilling, DeMarse, and LaClaire (in preparation) work led to the conclusion that midsegments are weighted more heavily as features than vertices. Wasserman, DeVolder, van Hamme, and Biederman (1990) studied vertex and midsegments using more complex figures than Rilling, DeMarse, and LaClaire, but came to the same conclusion. Blough's (in press) conclusion is that higher level relations of features, like symmetry, are critical to pigeons performance in target detection tasks. Indeed, the present investigation suggests that the higher level relation between features which is defined as the relative degree of proximity of a part given the figure containing that part may be important for pigeons in the process of discriminating between visual forms.

Feature theories of animal object recognition have not yet been formalized as the initial data base for generating such a model has not been completely formed. It is only in very recent work that low level features have been tentatively identified using two-dimensional line drawings. There may be a different set of elementary features available in actual three dimensional objects as suggested by Biederman's (1987) recognition-by-components theory of human object recognition in which he argues for the use of a three-dimensional primitive called a geon. Geons are defined as a particular set of generalized cones. In order to provide an adequate test of this notion either three-dimensional objects need to be used, or strong evidence for animals being able to detect the three-dimensional structure of two-dimensional drawings needs to be provided.

Furthermore, it would be premature to make any conclusions about the precise nature and dimensions used in generating higher level representations based on these low level features. There are a number of promising means by which pigeons may organize features like symmetry, proximity, and connectedness. But, other means of organizing features need to be investigated like complexity, axes of elongation, non-accidental properties, and redundancy. Ultimately, whatever organizing principles are identified as being best able to account for the results of further empirical work will need to be integrated into an account of the stages of the feature analytic process which is assumed to result in a unitary representation of the object or scene.

Furthermore, the issue of the frame of reference used in the process of object recognition has not been directly investigated. Template theories like Heinemann and Chases' (1990) clearly prefer the use of viewer-centered coordinates. Feature models tend to be more amenable to the use of object-centered coordinates. The main advantage of the object-centered coordinate system is in terms of an economy of storage as viewer-centered coordinates require multiple representations for an object as the viewer's spatial relationship with the object changes. While there is some evidence (Vaughn & Greene, 1984) that pigeons may be capable of impressive feats of storage, there is no reason to assume that either the process underlying those feats is memory intensive or that this is ecologically valid. Furthermore, evidence from sub-categorization experiments, and pseudo-categorization control groups (Wasserman, Kiedinger, & Bhatt, 1988) clearly implicates the existence of some metric of similarity influencing the pigeon's memory for category membership. It is highly likely that both object and viewer centered coordinate systems are available for use in the perceptual systems of animals as both types of information are important for functioning in the real world. However, template matching theories have difficulty in dealing with the development of object-centered representations. Whereas feature analytic theories are capable of providing both types of coordinate systems.

In conclusion, the present research is an important step forward in the pursuit of a feature analysis model for object recognition in animals. The main result of the experimental work is only suggestive of the pigeons use of high level organizing principles in object recognition processes. This work fits well with Blough's (in press) evaluation of the process of object recognition in pigeons. It extends our knowledge of the processes whereby higher level representations are generated which Heinemann and Chases' (1990) template matching theory leaves largely undescribed. Furthermore, theoretical arguments and other indirect evidence against the use of a strict template matching theory have been presented. But, a formal model of object recognition in pigeons based on feature analysis is not presented as more research is needed in order to make a strong proposal regarding the exact nature of this process. Suffice it to say that feature analysis has been implicated as being the process underlying pigeons visual object recognition capabilities.

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APPENDICES

APPENDIX A

APPENDIX A
Instructions for running PRII.05b.obj

1. The first screen -- Subject/Time/Place data. This screen is fairly self-explanatory. Note: Never enter the same session number twice, and keep session numbers under 100.

2. The second screen -- Saving your data. This screen shows you which disk it will save your data on and asks you for a title. Since you'll probably want to save your data on a data disk in the external drive, you may need to click on the "drive" button. Always include the date and your bird's number when giving the data a title. For example: "A1137 4/11/91 test" is a proper data file title which indicates the subject's number (A1137), the date of the session (4/11/91), and that this was a test session.

3. The third screen -- Activating the touch screen. What the computer needs at this point are the coordinates that define the active touchscreen. These can vary depending on your purpose, but default coordinates are 0, 70, 0, and 60. If you do not know how much of the touchscreen to activate, enter these coordinates in the order given and press <u>Return</u> after <u>each</u> number. Coordinates for each experiment being run should be available on the 'experiment info sheet' which can be found in the green binder.

4. The fourth screen -- Trial types and block size. Next, the computer will ask you how many "trial types" you want to run. What this means is that the computer needs to know how many different contingencies you want to run. Each picture-contingency pairing is one trial type. For example, during discrimination training, you are running two different contingencies: An S+ that is reinforced and an S- that isn't (trial types = 2). If you add a probe to the previous example, then you have three contingencies: an S+ that is reinforced, an S- that isn't, and a probe that isn't (trial types = 3). The picture which is being used as the S+ stimulus may also be used for the non-reinforced probe trial in this example (trial type still = 3) -- this is an example of an S+/extinction trial introduced to stabilize performance during probe testing. Also, if more stimuli (pictures) are to be introduced which all have the same contingency (S+, S-, or Probe), each one is a unique trial type. So, if we had two different probe pictures (let's call them picture A and picture B) which we wanted to run during a testing session which also had one S+ picture, one S- picture, and the S+ picture as a probe (an S+/extinction trial), then this session would have five trial types: 1. the S+, 2. the S-, 3. the S+/extinction (using the S+ picture declared as a probe type), 4. picture A declared as a probe type, and 5. picture B declared as a probe type.

After you enter the number of trial types, the computer asks for "block size." Block size determines how many times in a row the same stimulus will be presented. The larger the block, the greater the ease of learning. Remember that the block size and the total number of trials are related -- for example you cannot have a block of size 8 with 50 total trials because 50 is not evenly divisible by 8. The total number of trials must be evenly divisible by the block size.

5. The fifth screen -- Setting up the pictures. The following screens repeat over and over until the number of trial types that you requested in step four have been specified. What happens in this loop is that you actually select the contingency and the picture to go along with it.

a. Type of stimulus: Read the screen; it's self-explanatory. It's a good idea to always enter your stimuli in the same order so you won't make mistakes.

b. Milliseconds: 1,000 milliseconds = 1 second. Enter the amount of time you want the stimulus to stay on the screen in milliseconds.

c. Choosing the picture(s) -- this screen is similar to the "saving data" screen. It lets you view the contents of both disks to find where your pictures are. Again, you can change the active disk drive by clicking on the "drive" button. When you find the picture(s) you are going to use, double click on their titles to activate them. The computer only acknowledges one picture at a time, so if you are using moving stimuli, choose the pictures in the correct order. After you are done choosing the picture(s) for the trial type you are working on, click on the "cancel" button.

d. The last piece of information needed in this loop is how many trials of the stimulus that you just chose are needed to appear throughout the entire session. After you enter this number, the computer will return to step (a) and ask for all of the same information on the next trial type. When all of the trial types have been specified, the loop ends.

6. The sixth screen -- Randomized trials. The computer now presents you with the randomly generated trials. They whiz by pretty fast, but don't worry. Glance at them to make sure they look random. Enter any number to continue.

7. The seventh screen -- Final check. The computer finally presents you with a summary of how the program will run. Look carefully at what is listed; make sure the contingencies, pictures, and number of trials are correct. If everything looks okay, enter any number to begin the experiment.

SOURCE CODE FOR PRII.05B

```
Program cycling;

(*     This is a program designed to utilize the graphics
capabilities of the MacIntosh, to present stimuli, touch
sensitive technologies for recording responses, and the
BenchtopTM instrument for providing a real world interface
for doing discrimination and generalization research. *)

(* Compiler Instructions *)
Uses __Quickdraw, __Graphutils,  __SaneIO,  __Tooltraps,
     (*$U+*) uQuickdraw,  uPackIntf;

(* Linker Instructions *)
Link  __Benchlib, __Touchlib.51290, __Quickdraw,
      __Graphutils, __IO,  __OSTraps, __Scrollwind, __Sane,
      __Uniform, __ExtendIO, __Extras, __Stringlib,
      __SFNames, __NoSysCall, __PackTraps  : PRII.05b.obj;

(* Declaration of Globally Defined Constants *)
Const

     (* Trial Information Constants *)
     sPlus = 0;
     sMinus = 1;
     probe = 2;
     moving = 1B;
     stationary = OB;

     (* Touch Screen Constants *)
     Enterpoint = 37;
     tracking = 39;
     exitpoint = 40;
     addexit = 1;
     subexit = 5;
     reportranson = 1;
     reportransoff = 5;
     coordmode = 35;
     scanmode = 34;

     (* Graphics Constants *)
     patC = 8;   (* Black *)
     patB = 11;  (* White *)

     (* Declaration of Variable Type for this program's *)
     (* specific use.                                   *)

Type

    (*      Variable type "trialinfo" is used to store *)
    (* information about each unique type of trial     *)
```

```
    (* entered by the user for any given session.      *)


    trialinfo = record
               number:Integer;
               type:Integer;
               numpicts:Integer;
               duration:Longint;
               motion:byte;
               nameptr:stringptr;
               name:Str255;
               stimulus:pichandle[101]
               wrongstim:pichandle[101]
               End;

(* Global Variable List *)
Var rft,ttypes,lasterr,tottrials,blocks,blocktrials:Integer;
    tct1,tct2,tct3,hix,lox,hiy,loy:Integer;
    rndnoa,brndno:Integer;
    current:trialinfo[301]
    vref,good,ID,cue,count:Integer;
    neg,pos,prob:Integer[500];
    typetot:Integer[25];
    order:Integer[500];
    Amt:Longint;
    numbit,timebit:Longint[400];
    destined:byte[400];
    Destination:integer[400];
    nameptr:ptrL;
    rectframe,pfr,rde:rect;
    hiddenport,execport:grafptr;
    blacker,whiter:Pattern;
    LReply:SFReply;

(* List of Externally Defined Functions *)

Function  Random():Integer;
EXTERNAL;

Function   Black():^Pattern;
EXTERNAL;

Function   White()^Pattern;
EXTERNAL;

Function  CheckIn(first,in,last:Integer):Integer;
EXTERNAL;

Function  Evenodd(val:Integer):Integer;
EXTERNAL;

Function FSread(refnum:Integer;counter:Ptr1;buffptr:Ptr):
               integer;
```

```
 EXTERNAL;
Function  Openpicture(Picframe:rect):    Pichandle:
EXTERNAL;

Function Newhandle((size:longint):Handle;
EXTERNAL;

(*     A procedure to obtain the amount *)
(* of information in the A-port input   *)
(* buffer from the touchscreen.         *)

Procedure  Aserwaiting(num:^Longint);
     {
      setserport(0);
      serwainting(num);
     };

 (*    A procedure to remove a block *)
 (* of data from the A-port input    *)
 (* buffer to variable space.        *)

Procedure  Agetblock (des:PtrB;mun:PtrL);
     {
      lasterr:=FSRead(-6,mun,des);
     };

(* Initialization Procedure *)

procedure  _Init();

var beta,numrand,sessnum,peat:Integer;
    bird,dday,weight,sesstime,chamber,repeat,halfnum,
    testnum,typing:Integer;
    mark:Integer[200];

{
(* Initialize BenchtopTM Instrument. *)
Wakebench(cue);
(* Initialize the Touch Screen. *)
Wakescreen(reportranson,coordmode,enterpoint,subexit);
clear();
(* Initializes Trigonometric Functions *)
InitTrig();
Moveto(10,10);
(* Collect information about the active area for the touch
screen. *)
Writestring("Enter the leftmost (lowest) active touch screen
             coordinate:");
readint(@lox);
Writestring("Enter the rightmost (highest) active touch
            screen coordinate:");
readint(@hix);
Writestring("Enter the topmost (lowest) active touch screen
```

```
            coordinate:");
readint(@loy);
clear();
moveto (10,10);
(*
Collect information about the number of kinds of trials.
*)
Writestring("Enter the number of trail types you want:
            (1-20) ");
readint(@ttypes);
writeln();
(* Collect Information about the block structure of the
session. *)
Writestring("Enter the size of trialtype blocks desired;
            (1 is random) ");
readint(@blocks);
writeln();
(* Begin to initialize variables. *)
tct1:=0;tct2:=0;tct3:=0;
loop(,repeat:=0,++repeat,repeat>=25)
    {
    typetot[repeat]:=0;
    };
loop(,repeat:=0,++repeat,repeat>=200)
    {
    mark[repeat]:=0;
    };
loop(,repeat:=0,++repeat,repeat>=70)
    {
     pos[repeat]:=0;
     neg[repeat]:=0;
     prob[repeat]:=0;
    };
loop(,repeat:=0,++repeat,repeat>=100)
    {
     order[repeat]:=0;
    };
clear();
tottrials:=0;
halfnum:=0;
testnum:=0;
(* End initialization of variables. *)


(************************************************************)
(*      Begin loop to collect information about each kind *)
(* or type of trial to be run during the session.  The    *)
(* following information is collected and stored in       *)
(* variable space:  The type of trial (positive, negative,*)
(* or probe), the duration of the trial, the stimulus to  *)
(* be used in terms of 'PICT' file(s) indicating the use  *)
(* of static or moving forms, and the number of times     *)
(* that the trial should be repeated within the session.  *)
```

```
(************************************************************)
loop(,repeat:=1,beta:=1,++repeat,repeat>ttypes)
    {
     clear();
     moveto(10,10);
     writestring("What type of stimulus do you want this to
                  be?");
     writeln();
     writesting("--  Enter a 1 for an S+, A 2 for a S-, or a
                 three for a probe:");
     readint(@typing);
     case typing of
          1:current[repeat].type:=sPlus;
          2:current[repeat].type:=sMinus;
          3:current[repeat].type:=probe;
          otherwise  { writeln();
                       writestring("O.K. wiseguy, this is
                                    going to be a probe,
                                    like it or not!");
                       current[repeat].type:=probe;
                     };
          END;
     clear();
     moveto(10,10);
     writestring("Enter the desired trial duration in
                  milliseconds:");
     writeln();
     readlong(@current[repeat].duration);
     clear();
     setpictures(repeat); (* Procedure to obtain
                             PICT file(s) *)
     if current[repeat].numpicts=1  then
        {current[repeat].motion:=stationary;
         sConCat(current[repeat].name,".Static",
                 current[repeat].name);
        }
        else
        {current[repeat].motion:=moving;
         sConCat(current[repeat].name,".Moving",
                 current[repeat].name);
        };
     case current[repeat].type of
          sPlus:sConCat(current[repeat].name,".S+",
                        current[repeat].name);
          sMinus:sConCat(current[repeat].name,".S-",
                         current[repeat].name);
          probe:sConCat(current[repeat.name,".Probe",
                        current[repeat].name);
     END;
     clear();
     moveto(10,10);
     writestring("How many trials of this stimulus would you
                  like? (max/type=70)");
```

```
    readint(@current[repeat]/number);
    tottrials+=current[repeat].number;
    if tottrials>200 then
       writesting("May not work properly with over 200
                   trials!");
    resettimer();
    attime 1000 do;
    if current[repeat].number<>0 then
       halfnum:=current[repeat].number/2;
    loop(current[repeat].number>0,testnum:=1,(++testnum;
        ++beta),beta>tottrials)
        {
         order[beta]:=repeat;
        };
    };
(*  End trial type information collection loop. *)

clear();

(* Begin to collect subject, and date information for
   session. *)
moveto(10,10);
writestring("Enter Bird's no.");
readint(@bird);
writeln();
writestring("Enter Bird's Weight:);
readint(@weight);
writeln();
writestring("Enter Date:(i.e., 327 for Mar 27)");
readint(@dday);
writeln();
writestring("Enter time:(i.e., 1200 for 12:00)");
readint(@sesstime);
writeln();
writestring("Enter Session Number: (1 for the first session,
             etc.)");
readint(@sessnum);
writeln();
Writestring("Enter the box designation:  (1 for box 1a, 2
             for box 1c)");
readint(@chamber);
writeln();
(* Finish collecting subject and date information for the
   session. *)

(* Create data file for the session. *)
putfile (@nameptr, @Vref, @good);
if good then
        {
         fcreate(nameptr," RCMP"+2, "TEXT"+2,vref);
         fopen(@ID,nameptr,3,vref);
        };
Amt:=0;
```

```
(* Store subject and date information in the data file. *)
Basicdata(ID,bird,weight,dday,sesstime,sessnum);
clear();

(* Instruct the BenchtopTM to turn on panel light.*)
turnon(0,56,cue);
blocktrials:=tottrials/blocks;
numrand:=sessnum*(blocktrials*2);

(* Call procedure to obtain random ordering of trials. *)
loop(,repeat:=0,++repeat,repeat>=numrand(),
     randomization(););
clear();
numrand:=0;


(* Loop to display the ordering of the trial types. *)
loop(,repeat:=1,++repeat,repeat>tottrials)
    {
     writeint(order[repeat]);
     numrand+=1;
     if numrand>=blocks then(numrand:=0;writeln(););
     typetot[order[repeat]]+=1;
     if order[repeat]<0 then mark[repeat]:=repeat;
    };
(* End loop. *)

writeln();
writestring("Enter any number to continue:");
readint(@repeat);
clear();
loop(,repeat:=1,++repeat,repeat>ttypes)
    {
    loop(typetot[repeat]<>current[repeat].number,peat:=1,
         ++peat, peat>tottrials)
        {
         If (mark[peat]<>0) then
            {
             order[mark[peat]]:=repeat;
             typetot[repeat]+=1;
            };
         If typetot[repeat]=current[repeat].number then
            BREAK;
        };
    };

(* Loop to list the session information out to the
  screen. *)
loop(,repeat:=1,++repeat,repeat>ttypes)
    {
     Writestring("Trial type");
     writeint(repeat);
```

```
     writestring(", called");
     writestring(current[repeat].name);
     writestring(", has");
     writeint(typetot[repeat]);
     writestring("trials scheduled for this session.");
     writeln();
    };
(* End Loop. *)

writeln();
writestring("Enter any number to continue:");
readint(@repeat);
clear();
loop(,repeat:=0,++repeat,repeat>=25)
    {
     typetot[repeat]:=0;
    };
repeat:=10;

(* Initialize Graphics Ports for use. *)
getport(@execport);
getrect(@pfr);
getrect(@rectframe);
loop(,repeat:=0,,repeat<>0)
    {
     hiddenport:=newoffport(pfr);
     if hiddenport then
        { setport(execport);
          moveto(10,10);
          Writestring("ERROR, Enter a 0 to try again, 1 to
                      Break:");
          readint(@repeat);
        }
        else repeat:=5;
    };
if repeat=1 then reqhalt();
clear();
setport(execport);

(* End Initialization Procedure. *)
};

(* The following procedure 'shuffles' the order of the
   trials so that the order of the trial types is completely
   random. *)

procedure randomization();
var hold,spacer,rndcter:Integer;
{
hold:=0;
spacer:=0;
rndcter:=0;
loop(,,,rndnoa<>brndno)
```

```
     {
      loop(,rndnoa:=-1,rndnoa:=random()  mod
           blocktrials,rndnoa>0);
      loop(,brndno:=-1,brndno:=random()  mod
           blocktrials,brndno>0);
     };
rndnoa:=rndnoa*blocks;
rndnoa:=rndnoa-blocks;
rndnoa:=rndnoa+1;
brndno:=brndno*blocks;
brndno:=brndno-blocks;
brndno:=brndno+1;
loop(,rndcter:=1,++rndcter,rndcter>blocks)
     {
      hold;=order[rndnoa];
      spacer:=order[brndno];
      order[brndno]:=hold;
      order[rndnoa]:=spacer;
      rndnoa+=1;
      brndno+=1;
     };
};

(*      The following procedure allows the user to select *)
(* 'PICT' files from the available files stored on disk   *)
(* to use for each trial type.  The information stored in *)
(* these files is then moved to active variable space in  *)
(* the program for use at any point as required by the    *)
(* user.  Multiple 'PICT' files may be selected to        *)
(* produce trials which display apparent motion.          *)

Procedure  Setpictures(homeboy:Integer);
var  pvref,nrefn,gd,cter:Integer;
     len:Longint;
     where:Point;
     exts:str255;
     pictname,extension:stringptr;

{
moveto(10,10);
writestring("Enter number of pictures for this stimulus:");
readint(@current[homeboy].numpicts);
clear();
moveto(10,10);
nrefn:=1;
getrect(@rde);
where.v:=70;
where.h:=100;
pictname:=@Lreply.fname;
Current[homeboy].nameptr:=@Current[homeboy].name;
loop(,cter:=1,++cter,cter>current[homeboy].numpicts)
     {
      SFgetfile(where.vh"",Nil,2,"   PICT"+2,nil,@Lreply);
```

```
     if !Lreply.good  then
        {
         gd:=-1;
         return;
        };
     pvref:=Lreply.vrefnum;
     fopen(@nrefn,pictname,1,pvref);
     ferr(@gd);
     flength(nrefn,@Len);
     fmoveto(nrefn,512L);
     Len-=512;
     current{homeboy].stimulus[ctr[:=NewHandle(Len);
     Hlock(current[homeboy].stimulus[ctr]);
     fread(nrefn,current[homeboy].stimulus[ctr]^,@Len);
     Hunlock(current[homeboy].stimulus[ctr]);
     fclose(nrefn);
     writesting("Picture  ");
     writeint(cter);
     writestring("  of Stimulus ");
     writeint(homeboy);
     writestring("  is set.");
     writeln();
    };
Copystr(pictname,Current[homeboy].nameptr);
};

(*     The following procedure is the procedure that      *)
(* produces the display for each trial, collects data,    *)
(* and defines the appropriate consequence for that trial *)
(* type.                                                  *)

Procedure  Picturethat();
var sickrect:Rect;
    account,ohno,xres,yres,quo,ct,side,trialstim,
    swl:Integer;
    waiter,statwait:Longint;
{
account:=0;ohno:=0;xres:=-1;yres:=-1;quo:=1;
trialstim:=order[count];
setrect(sickrect,100,30,130,60);
AserWaiting(@waiter);
loop(,,--waiter,waiter<=0)
    {Anodwellchar(@ct);
     If ct=-1  then BREAK;});
Resettimer();
ct:=0;
setport(hiddenport);
ct:=1;
swl:=2;
loop(current[trialstim].motion=moving,account:=0,++account,
     rft=1)
    {
     clear();
```

```
drawpicture(current[trialstim].stimulus[ct],rde);
loop(,waiter:=TickCount(),,TickCount()>=waiter+3);
copybits(hiddenport^.portbits,execport^.portbits,
         pfr,pfr,srccopy,nil);
Aserwaiting(@numbit[account]);
Timerval(@timebit[account]);
If swl=1 then --ct
         else ++ct;
If ct=current[trialstim].numpicts then swl:=1;
If ct=1 then swl:=2;
If timebit[account]>=current[trialstim].duration  then
   {
    if ohno=0 then
       {
        amt:=numbit[account];
        if (amt<=400) then
           lasterr:=FSRead(-6,@amt,@destined)
           else
           {
            fputc(ID,13);
            fputs(ID,"Response Overload, only part of
                      responses recorded.");
            fputc(ID,13);
            amt:=360;
            lasterr:=FSRead(-6,@amt,@destined);
            amt:=numbit[account]-amt;
            amt/=4;
            fputi(ID,amt);
            fputs(ID"Responses were not recorded,
                      approximately.");
            fputc(ID,13);
           };
        serflush();
        xres:=-1;
        yres:=-1;
       };
    ohno:=1;
    Case current[trialstim].type of
         splus:{
                recording(1,@xres,@yres);
                loop(,waiter:=TickCount(),,TickCount()>
                      waiter+1);
                if (xres>=lox) and (xres<=hix) and
                   (yres>=loy) and (yres<hiy) then
                   {
                    side:=evenodd(count);
                    if side<=0 then side:=2;
                    clear();
                    copybits(hiddenport^.portbits,
                             execport^.portbits,
                             pfr,pfr,srccopy,nil);
                    reinforce(quo,300,side);
                    rft:=1;
```

```
                    };
                };
            sminus,probe:{
                          clear();
                          copybits(hiddenport^.portbits,
                                   execport^.portbits,
                                   pfr,pfr,srccopy,nil);
                          rft:=1;
                          BREAK;
                         };
            END;
      };
   if current[trialstim].motion=stationary then
      {
       drawpicture(current[trialstim].stimulus[1],rde);
       copybits(hiddenport^.portbits,execport^.portbits,
                pfr,pfr,srccopy,nil);
       loop(,waiter:=TickCount(),,TickCount()>+waiter+3);
    };
   Resettimer();
   loop(current[trialstim].motion=stationary,account:=0;
        statwait:=50,++account,)
        {
        Aserwaiting(@numbit[account]);
        Timerval(@timebit[account]);
        if timebit[account]>=current[trialstim].duration
           then BREAK;
        Attime statwait do statwait+=50;
        };
   if current[trialstim].motion=stationary the
        {
        amt:=numbit[account];
        if (amt<400) then lasterr:=
                          FSRead(-6,@amt<@destined)
                      else
                      {
                       fputc(ID,13);
                       fputs(ID,"Response Overload, only
                             part of responses recorded.");
                      fputc(ID,13);
                       amt:=360;
                       lasterr:=FSRead(-6,@amt,@destined);
                     amt:=numbit[account]-amt;
                       amt/=4;
                       fputi(ID,amt);
                       fputs(ID,"Responses were not
                             recorded, approximately.");
                       fputc(ID,13);
                      };
        serflush();
        xres:=-1;
        yres:=-1;
        };
```

```
     loop(current[trialstim].motion=stationary,,,rft=1);
         {
          If current[trialstim].type=splus the
             {
              recording(1,@xres,@yres);
              loop(,waiter:=TickCount(),,TickCount()>
                   waiter+1);
              if (xres>=lox) and(xres<=hix) and (yres>=loy)
                 and yres<hiy then
                 {
                  side:=evenodd(count);
                  if side<=0 then side:=2;
                  clear();
                  copybits(hiddenport^.portbits,execport^.
                           portbits,pfr,pfr,srccopy,nil);
                  reinforce(quo,300,side);
                  rft:=1;
                  BREAK;
                 };
             }
             else
             {
              clear();
              copybits(hiddenport^.portbits,execport^.
                       .portbits,pfr,pfr,srccopy,nil);
              rft:=1;
              BREAK;
             };
         };
     Timerval(@waiter);
     fputs(ID,"Stimulus duration was");
     fputl(ID,waiter);
     fputs(ID,"milliseconds.");
};

(*     The following procedure examines the data   *)
(* collected  during each trial and filters it and *)
(* stores it in the data file.                     *)

Procedure figure();
var intr,bone,bold,smooth,lamt,actuary,cuteout,ts:Integer;
    skip,out:Longint;
{
cuteout:=0;out:=3000;ts:=order[count];
Resettimer();
Attime 500 do;
lamt:=amt;
turnon(48,48,cue);
smooth:=5;bone:=1;actuary:=1;
Resettimer();
Attime 500 do bold:=0;
loop(lamt>0,intr:=0++intr,intr>=lamt)
    { destination[intr]:=destined[intr]; };
```

```
intr:=0;
loop(lamt>0,actuary:=1,++actuary,intr>lamt)
     {
      if numbit[actuary]>0 then
          {
           loop(,,++intr,intr>numbit[actuary])
               {
                cuteout:=cuteout+1;
                arrivaltime[intr]:=timebit[actuary];
                if cuteout>=8 then
                    {
                     cuteout:=0;
                     writeln();
                    };
               };
          };
     };
loop(lamt>0,intr:=0,++intr,intr>lamt)
     {
      smooth:=0;
      loop(,bone:=1,++bone,smooth=1)
          {
           If (destination[intr]>=245) or
               (destination[intr]<3) then
               {
                bold:=intr+bone:
                destination[intr]:=destination[bold];
                arrivaltime[intr]:=arrivaltime[bold];
                destination[bold]:=255;);
                If (destination[intr]:=<245) and
                   (destination[intr]>3) then smooth:=1;
                If destination[intr]=300 then smooth:=1;
                If bold>amt then smooth:=1;
               };
          };
     };
Attime 500 do cuteout:=0;
fputs(ID,"Trialnumber");
fputi(ID,count);
case current[ts].type of
      sminus:(fputs(ID,",  S-.");tct1+=1;);
      splus:(fputs(ID,",  S+,");tct2+=1;);
      probe:(fputs(ID,",  Probe,");tct3+=1;)
end;
Fputs(ID,current[ts]].name);
fputc(ID,13);
loop(destination[0]<>300,intr:=0,,destination[intr])>=245)
     {
      if destination[intr]<=0 then BREAK;
      if intr>lamt then BREAK;
      if destination[intr]=255 then BREAK;
      fputi(ID,destination[intr]);
      fputc(ID,09);
```

```
     fputL(ID,arrivaltime[intr+1]);
     fputc(ID,09);
     fputL(ID,arrivaltime[intr]);
     fputc(ID,09);
     fputL(ID,arrivaltime{intr+1]);
     fputc(ID,13);
     intr:=intr+2;
    };
Case current[ts].type of
     sminus:{if intr<>0 then neg[tct1]:=(intr/2);
             fputs(ID,"There were a total of");
             fputi(ID,neg[tct1]);
             fputs(ID,"responses throughout this trial.");
             timerval(@out);
             if neg[tct1]>5 then out:=out+(neg[tct1]*1000);
           Resettimer();
             loop(,,timerval(@skip),skip>=out)
             typetot[ts]+=neg[tct1];
            };
      splus:{if intr<>0 then pos[tct2]:=(intr/2)+rft
                        else pos[tct2]:=rft;
             fputs(ID,"There were a total of");
             fputi(ID,pos[tct2]);
             fputs(ID,"responses throughout this trial.");
             typetot[ts]+=pos[tct2];
            };
      probe:{if intr<>0 then prob[tct3]:=intr/2;
             fputs(ID,"There were a total of");
             fputi(ID,prob[tct3]);
             fputs(ID,"responses throughout this trial.");
             typetot[ts]+=prob[tct3];
            };
END;
fputc(ID,13);
fputs(ID,"Total to this type =");
fputi(ID,typetot[ts]);
fputc(ID,13);
};

(*   The following procedure resets variable array space  *)
(* to allow that space to be reused anew on each new      *)
(* trial.                                                 *)


Procedure Resetarrays();
var cutting,orct:Integer;
    creased:Longint;
{
 orct:=order[count];
 loop(,cutting:=0,++cutting,cutting>=400)
     { destination[cutting]:=300;
       arrivaltime[cutting]:=-1; };
 loop(,cutting:=0,++cutting,cutting>=500)
```

```
     { numbit[cutting]:=-1;
       timebit[cutting]:=-1; };
 Aserwaiting(@creamed);
 loop(,,--creamed,creamed<=0)
     { Anodwellchar(@cutting);
       if cutting<0 then BREAK; };
};

(*     The following procedure is the MAIN body of the    *)
(* program. It structures the flow of processing occurring
*) (* when the program is run following the initialization
*) (* sequence.
*)

Procedure  Main();
var cutout,slop:Integer;
    drect;Rect:
{
cutout:=0;
count:=1;

(* Insure that the array space is ready for use. *)
Resetarrays();

(* Wait 3 seconds to proceed. *)
resettimer();
attime 3000 do;

(* Turn on the houselight. *)
turnon(56,48,cue);

(* Main loop. *)
loop(,count:=1,++count,count>tottrials)
    {

     (* Reset array space each time through the loop. *)
     Resetarrays();
     clear();
     (* Present a trial. *)
     Picturethat();

     (* Store the trial's data. *)
     figure();

     (* Turn on the houselight. *)
     turnon(56,48,cue);
    };

(* Call the  Halt() procedure to finish the session. *)
Reqhalt();
};

(*  The following procedure terminates the session.  It   *)
```

```
(* has two primary functions: To take care of programming,*)
(* equipment and computer operating needs, and to provide *)
(* session summary data both as stored in a data file and *)
(* as screen output.                                      *)


Procedure   Halt();

var cutter,totpos,totneg,totpro,outs,ocut:Integer;

{
Setport(execport);
Diposeoffport(hiddenport);
whiter:= White()^;
backpat(whiter);
clear();      outs:=0;totpro:=0;totpos:=0;totneg:=0;
tct1:=0;tct2:=0;tct3:=0;
Fputc(ID,13);
fputs(ID,"***************   SUMMARY  ***************");
fputc(ID,13);
fputs(ID,"Trial:");
fputc(ID,09);
fputs(ID,"variety")
fputc(ID,09)
fputs(ID,"Responses");
fputc(ID,13);
loop(,cutter:=1,++cutter,cutter>tottrials)
    {
     fputs(ID,"     ");
     fputc(ID,09);
     fputi(ID,cutter);
     fputs(ID,",");
     fputc(ID,09);
     ocut:=order[cutter];
     fputs(ID,current[ocut].name);
     fputc(ID,09);
     Case current[ocut].type of
          sminus:{ tct1+=1;
                   fputs(ID,"    S-,  ");
                   fputc(ID,09);
                   fputi(ID,neg[tct1]);
                   fputc(ID,13);
                   totneg:=totneg+neg[tct1];
                 };
           splus:{ tct2+=1;
                   fputs(ID,"    S+   ");
                   fputc(ID,09);
                   fputi(ID,pos[tct2]);
                   fputc(ID,13);
                   totpos:=totpos+pos[tct2];
                 };
           probe:{ tct3+=1;
                   fputs(ID,"      Probe,   ")
```

```
                    fputc(ID,09);
                    fputi(ID,prob[tct3]);
                    fputc(ID,13);
                    totpro:=totpro+prob[tct3];
                  };
     END;
};
fputc(ID,13);
fputs(ID,"There were");
fputi(ID,totpos);
fputs(ID,totpos);
fputsI(ID,"  responses during S+.")
fputc(ID,13);
fputs(ID,"There were");
fputi(ID,totneg);
fputs(ID,"responses during S-,");
fputc(ID,13);
fputs(ID,"There were");
fputi(ID,totpro);
fputs(ID,"responses during Probes.");
fputc(ID,13);
loop(,cutter:=1,++cutter,cutter>ttypes)
    {
     fputs(ID,"There were");
     fputi(ID,typetot[cutter]);
     fputs(ID,"responses during");
     fputs(ID,current[cutter].name);
     fputc(ID,13);
    };
fputc(ID,13);
Moveto(10,10);
writesting("S+  Responses:")
writeint(totpos);
writeln();
writestring("S-  Responses:");
writeint(totneg);
writeln();
writestring(:P  Responses:");
writeint(totpro);
writeln();
loop(,cutter:=1,++cutter,cutter,cutter>ttypes)
    {
     Writestring("There were");
     writeint(typetot[cutter]);
     writestring("responses during");
     Writestring(current[cutter].name);
     writeln();
     };

(* Call to terminate the BenchtopTM operations. *)
Bigturnoff(cue);

(* Call to terminate the Touch Screen operations. *)
```

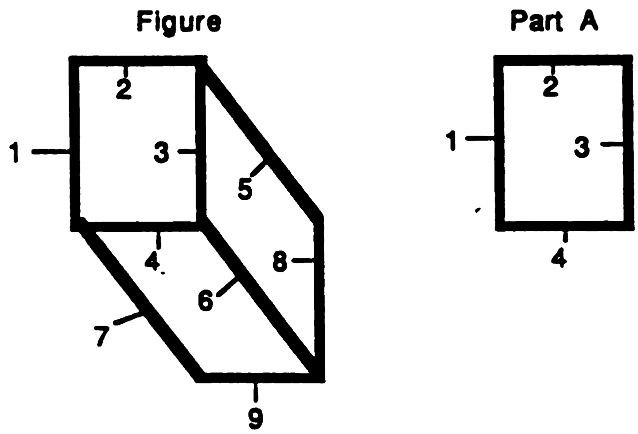
```
Aputchar(67);

(* Disconnect serial port communications. *)
closeserport(1);

(* Close the data file. *)
fclose(ID);
};

(* End of Program. *)
```

APPENDIX B

APPENDIX B

Clarification of Palmer's Model and Its Application

Proximity was defined as the euclidean distance between the midpoints of the segments as generated by the equation: $D=\surd(x1-x2)^2 + (y1-y2)^2$. Where D stands for distance, and (x1, y1) and (x2,y2) represent the cartesian coordinates of the midpoints of any two different segments in the figure. Thus, the distance between the leftmost vertical line (line 1) and the uppermost horizontal line (line 2) may be calculated from the knowledge of the locations of their midpoints. Line 1's midpoint is at x=0, y=1.9 or (0, 1.9). Line 2's midpoint is at x=0.9, y=2.5 or (0.9, 2.5). Inserting these values into the equation we obtain $D=\surd(0-0.9)^2+(1.9-2.5)^2$. This reduces to $D=\surd(-0.9)2+(-0.6)^2 = \surd 0.81+0.36 = \surd 1.17 = 1.08$. In order to obtain the scale value for the proximity dimension in Palmer's model, we need only multiply this distance by a -1.00, obtaining R(1,2)=-1.08. This process is carried out for all pairs of line segments in the figure. You may refer to Table B-1 for a listing of all of the scale values, R(i,j), of all of the pairs of segments, (i,j), in the figure used in this research.



Scale values for the proximity dimension between the above labled segments:

	1	2	3	4	5	6	7	8	9
1		-1.08	-1.80	-1.08	-2.70	-2.98	-1.54	-3.83	-3.30
2	-1.08		-1.08	-1.20	-1.91	-2.58	-1.85	-3.30	-3.08
3	-1.80	-1.08		-1.08	-0.90	-1.54	-1.54	-2.22	-2.10
4	-1.08	-1.20	-1.08		-1.88	-1.91	-0.65	-2.79	-2.22
5	-2.70	-1.91	-0.90	-1.88		-1.20	-2.16	-1.54	-1.85
6	-2.98	-2.58	-1.54	-1.91	-1.20		-1.80	-0.90	-0.65
7	-1.54	-1.85	-1.54	-0.65	-2.16	-1.80		-2.70	-1.91
8	-3.83	-3.30	-2.22	-2.79	-1.54	-0.90	-2.70		-1.08
9	-3.30	-3.08	-2.10	-2.22	-1.85	-0.65	-1.91	-1.08	

Table B-1: Proximity relations

The next step is fairly complicated. It involves finding the summed scale value for pairs of segments within a part, R(i,j), and the summed scale value for pairs of segments between the part and the remainder of the figure, R(i,k). Where i and j represent different pairs of segments in the part and k represents segments not in the part. Let us figure out these values for Part A. We already know the scale value of R(1,2)=-1.08. By looking in Table B-1 we find that the other within part scale values for proximity are: R(1,3)=-1.80, R(1,4)=-1.08, R(2,1)=-1.08, R(2,3)=-1.08, R(2,4)=-1.20, R(3,1)=-1.80, R(3,2)=-1.08, R(3,4)=-1.08, R(4,1)=-1.08, R(4,2)=-1.20, and R(4,3)=-1.08. The sum of all of the within part scale values is $R(i,j)_t$ = -14.64. Where $R(i,j)_t$ stands for the grand sum of all within part scale values. We can also find all of the between part scale values by reference to Table B-1: R(1,5)=-2.7, R(1,6)=-2.98, R(1,7)=-1.54, R(1,8)=-3.83, R(1,9)=-3.30, R(2,5)=-1.91, R(2,6)=-2.58, R(2,7)=-1.85, R(2,8)=-3.30, R(2,9)=-3.08, R(3,5)=-0.90, R(3,6)=-1.54, R(3,7)=-1.54, R(3,8)=-2.22, R(3,9)=-2.10, R(4,5)=-1.88, R(4,6)=-1.91, R(4,7)=-0.65, R(4,8)=-2.79, and R(4,9)=-2.22. Thus the grand sum of the between part scale values is $R(i,k)_t$ = -44.82.

Then R(i,j)t is multiplied by the number of segments in the figure, f, minus the number of segments in the part, p (or f-p). Giving the equation (f-p) * $R(i,j)_t$. This gives the number of between part comparisons which will be made.

There are a total of 9 segments in the figure and 4 segments in part A, or f=9 and p=4 which gives f-p = 9-4 = 5. Thus, there would be 5 between part comparisons for each within part scale value. Giving the result of (f-p) * $R(i,j)_t$ = 5*-14.64 = -73.2. $R(i,k)_t$ is then multiplied by p minus one which represents the number of times a within part scale value would be compared with each between part scale value. Giving the equation (p-1) * $R(i,k)_t$. There are 4 segments in part A. So, we would obtain (p-1) * R(i,k)t = 3 * -44.82 = -134.46. We then subtract the between part value from the within part value. Giving us {(f-p) * $R(i,j)_t$} - {(p-1) * $R(i,k)_t$} = -73.2 - (-134.46), or 134.46 - 73.2 = 61.26.

This result must then be divided by what amounts to the degrees of freedom remaining when a part having a given number of segments is used. This can be calculated by the equation p * (p-1) * (f-p). For a part with 4 segments taken from a figure with 9 segments, this equation gives 4 * (4-1) * (9-4) = 4 * 3 * 5 = 12 * 6 = 60. And the final equation and calculation for part A are represented by [{(f-p) * $R(i,j)_t$} - {(p-1) * $R(i,k)_t$}]/{p * (p-1) * (f-p)} = 61.26/60 = 1.02. It will be left up to the reader to apply this equation to any other parts which were used in these experiments.

APPENDIX C

APPENDIX C

Raw Data, Experiment One

Table C-1: Positive Generalization Response Rates

Proximity:	High	High	Low	Low
Separation:	Small	Large	Small	Large
		Session 1		
Pigeon Number				
1	51	52	41	41
2	41	56	29	48
3	47	53	42	41
4	55	49	55	61
5	26	35	17	27
6	58	58	35	53
7	32	29	47	46
		Session 2		
1	44	53	49	53
2	43	25	42	55
3	52	50	49	24
4	55	49	38	39
5	48	28	51	3
6	36	43	26	56
7	57	31	61	30
		Session 3		
1	50	41	49	43
2	32	38	29	37
3	44	51	32	35
4	54	61	61	13
5	51	38	51	24
6	45	1	26	32
7	20	55	50	32
		Averages and standard deviations		
1	48.3+/-3.1	48.7+/-5.4	46.3+/-3.8	45.7+/-5.3
2	38.7+/-4.8	39.7+/-12.7	33.3+/-6.1	46.7+/-7.4
3	47.7+/-3.3	51.3+/-1.3	41.0+/-7.0	33.3+/-7.0
4	54.7+/-0.5	53.0+/-5.7	51.3+/-9.7	37.7+/-19.6
5	41.7+/-11.2	33.7+/-4.2	39.7+/-16.0	18.0+/-10.7
6	46.3+/-9.0	34.0+/-24.1	29.0+/-4.2	47.0+/-10.7
7	36.3+/-15.4	38.3+/-11.8	52.7+/-6.0	36.0+/-7.1
Group	44.8+/-10.2	42.7+/-14.0	41.9+/-11.8	37.8+/-14.3

Table C-2: Negative Generalization Response Rates

Proximity:	High	High	Low	Low
Separation:	Small	Large	Small	Large
		Session 1		
Pigeon Number				
1	2	5	0	0
2	0	2	2	0
3	15	4	6	9
4	2	1	3	7
5	1	1	12	10
6	7	0	3	0
7	8	11	10	8
		Session 2		
1	5	7	15	2
2	15	4	0	5
3	4	9	6	10
4	12	5	33	30
5	0	2	0	0
6	0	0	0	2
7	7	18	7	4
		Session 3		
1	10	7	1	16
2	3	3	2	1
3	4	1	1	3
4	1	7	7	0
5	3	1	1	1
6	1	0	0	0
7	10	6	25	3

Table C-3: Response Latency and Distribution Data I

Latency is first value listed, all times are in milliseconds. Only responses to the first trial are listed.

Pigeon number 1:

Session one

High proximity, small separation: 1100, 1200, 1400, 1600, 1950, 2150, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 4100, 4300, 4500, 4700, 4900, 5100, 5300, 5500, 5700, 5900, 6100

High proximity, large separation: 800, 900, 1100, 1300, 1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900, 3100, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850

Low proximity, small separation: 700, 750, 950, 1150, 1350, 1700, 1900, 2100, 2300, 2500, 2700, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5200, 5550, 5750, 5950, 6150, 6350

Low proximity, large separation: 500, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4950

Session two

High proximity, small separation: 3650, 3700, 3900, 4100, 4300, 4500, 4700, 4900, 5100, 5300, 5500, 5700, 5900, 6100, 6300, 6500, 6700, 7050

High proximity, large separation: 1400, 1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900, 3100, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250, 6450, 6650

Low proximity, small separation: 700, 800, 1000, 1500, 1700, 2050, 2550, 2750, 2950, 3150, 3500, 3700, 4050, 4250, 4600, 4950, 5300, 5500, 5700, 5900, 6250, 6450

Low proximity, large separation: 1000, 1100, 1300, 1500, 1700, 1900, 2100, 2450, 2650, 2850, 3050, 3250, 3600, 3800, 4000, 4350, 4550, 4750, 4950, 5300, 5500, 5700, 5900, 6100

Session three

High proximity, small separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2400, 2750, 3100, 3450, 3650, 4000, 4350, 4550, 4750, 4950, 5150, 5500, 5700, 5900

High proximity, large separation: 2700, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4350, 4550, 4750, 4950, 5300, 5500, 5700, 5900, 6100, 6300, 6650

Low proximity, small separation: 1300, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4950, 5150, 5350, 5550, 5750, 5950, 6150

Table C-3, (Cont'd).

Low proximity, large separation: 450, 500, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800

Pigeon number 2

Session one

High proximity, small separation: 1950, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850

High proximity, large separation: 700, 750, 950, 1150, 1350, 1550, 1750, 1950, 2150, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750

Low proximity, small separation: 800, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050

Low proximity, large separation: 800, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050

Session two

High proximity, small separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2550, 3050, 3400, 3600, 3800, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950, 6150, 6350, 6550, 6750, 6950

High proximity, large separation: 2000, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400, 5600, 5800, 6000

Low proximity, small separation: 2250, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950, 6150, 6350

Low proximity, large separation: 150, 250, 450, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450

Session three

High proximity, small separation: 500, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200

High proximity, large separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650

Low proximity, small separation: 6050, 6100, 6300, 6500, 6700, 6900, 7100, 7300, 7500, 7700, 7900, 8100

Table C-3 (Cont'd).

Low proximity, large separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650

Pigeon number 3

Session one

High proximity, small separation: 1400, 1450, 1650, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400, 5600, 5800, 6000, 6200

High proximity, large separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400, 5600, 5800, 6000

Low proximity, small separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450

Low proximity, large separation: 600, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250

Session two

High proximity, small separation: 350, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400

High proximity, large separation: 500, 750, 950, 1150, 1350, 1550, 1750, 1950, 2150, 2350, 2550, 2900, 3100, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450

Low proximity, small separation: 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3200, 3400, 3600, 3800, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950

Low proximity, large separation: >10,000 (no responses)

Session three

High proximity, small separation: 2450, 2500, 2700, 2900, 3100, 3300, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5400, 5600, 5800, 6000, 6200, 6550

High proximity, large separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4600, 4800, 5000, 5200, 5400, 5600, 5800

Low proximity, small separation: 400, 500, 700, 900, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4600, 4800, 5000, 5200, 5400, 5600, 5950, 6150

Table C-3 (Cont'd).

Low proximity, large separation: 900, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2550, 2750

Pigeon number 4

Session one

High proximity, small separation: 850, 900, 1100, 1300, 1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900, 3100, 3300, 3500, 3700, 3900, 4100, 4300, 4500, 4700, 4900

High proximity, large separation: 1850, 1950, 2150, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550

Low proximity, small separation: 600, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2600, 2800, 3300, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250, 6450, 6650, 7000

Low proximity, large separation: 300, 350, 550, 750, 1100, 1300, 1500, 1700, 1900, 2250, 2600, 2950, 3150, 3350, 3700, 4050, 4250, 4450, 4800, 5150, 5350, 5550, 5750, 5950, 6150, 6350, 6550, 6750, 6950, 7150

Session two

High proximity, small separation: 300, 350, 550, 750, 1100, 1750, 1950, 2300, 3100, 3300, 3800, 4150, 4500, 4700, 4900, 5100, 5300, 5650, 6000, 6350, 6700, 7050, 7250, 7450, 8000, 8200, 8400, 8600

High proximity, large separation: 700, 900, 1100, 1300, 1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900, 3100, 3300, 3500, 3850, 4050, 4250, 4450, 4800, 5000

Low proximity, small separation: 800, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2550, 3650, 4150, 4500, 5600, 5950, 6150, 7250, 7750

Low proximity, large separation: 3850, 5000, 5350, 5550, 5750, 5950, 6150, 6350

Session three

High proximity, small separation: 700, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950

High proximity, large separation: 150, 250, 450, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250

Low proximity, small separation: 700, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3550, 3900, 4250, 4600, 4800, 5000, 5200, 5400, 5750, 5950, 6150, 6500, 6700, 6900, 7100, 7300, 7500, 7700

Table C-3 (Cont'd).

Low proximity, large separation: 550, 900, 1250, 1600, 2100, 2900, 3550, 4200, 4400, 4750

Pigeon number 5

Session one

High proximity, small separation: 7450, 7500, 7700, 7900, 8100, 8300, 8500, 8700, 8900, 9100

High proximity, large separation: 1500, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400, 5600, 5800, 6000, 6200, 6400, 6600, 6800, 7000

Low proximity, small separation: 2300, 2400, 2600

Low proximity, large separation: 2400, 2500, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4800, 5150, 5500, 5700, 5900, 6100, 6300, 6500, 6700, 6900, 7100, 7300, 7500

Session two

High proximity, small separation: 3550, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250, 6450, 6650, 6850, 7050, 7250

High proximity, large separation: 2150, 2200, 2400, 2600, 2800, 3000, 3350, 3550, 3750, 3950, 4150, 4350

Low proximity, small separation: 1800, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250, 6450, 6650

Low proximity, large separation: 1750, 1850

Session three

High proximity, small separation: 2500, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5300, 5500, 5700, 5900, 6100, 6300, 6500, 6700, 6900, 7100, 7300, 7500, 7700

High proximity, large separation: 5600, 5700, 5900, 6100, 6300, 6650, 6850, 7050, 7250, 7450, 7650, 7850, 8050, 8250

Low proximity, small separation: 1500, 1600, 1800, 2000, 2200, 2400, 2750, 3250, 3750, 4100, 4450, 4950, 5150, 5350, 5550, 5750, 5950, 6150, 6350, 6550, 6750, 6950, 7150, 7350, 7550

Low proximity, large separation: 6200, 6300, 6500, 6700, 6900, 7100, 7300, 7500, 7700, 7900, 8100, 8300

Table C-3 (Cont'd).

Pigeon number 6

Session one

High proximity, small separation: 900, 950, 1150, 1350, 1550, 1750, 1950, 2150, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950, 6150, 6350

High proximity, large separation: 550, 650, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250

Low proximity, small separation: 1200, 1300, 1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900, 3100, 3300, 3500, 3700, 3900, 4100, 4300, 4500, 4700, 4900, 5100, 5300, 5500, 5700, 5900, 6100, 6300

Low proximity, large separation: 1300, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400, 5600, 5800, 6000, 6200, 6400

Session two

High proximity, small separation: 1250, 1350, 1550, 1750, 1950, 2150, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950, 6150

High proximity, large separation: 3800, 3900, 4100, 4300, 4500, 4700, 4900, 5100, 5300, 5500, 5700, 5900, 6100, 6300, 6500, 6700, 6900, 7100

Low proximity, small separation: 1550, 1650, 1850

Low proximity, large separation: 1200, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250

Session three

High proximity, small separation: 2300, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400, 5600, 5800, 6000, 6200, 6400, 6600

High proximity, large separation: 1350

Low proximity, small separation: 1450, 1500

Low proximity, large separation: 1000, 1050, 1250, 1450, 1650, 1850, 2050, 2250

Table C-3 (Cont'd).

Pigeon number 7

Session one

High proximity, small separation: 850, 900, 1100, 1200, 1400, 2350, 3000, 3650, 4150, 4350, 4550, 4900, 5250, 5600, 5800, 6000, 6200, 6400, 6600, 6800, 7000

High proximity, large separation: 500, 600, 800, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950, 6150, 6350, 6550

Low proximity, small separation: 650, 700, 900, 1250, 1450, 1650, 1850, 2051, 2850, 3200, 3700, 3900, 4250, 4450, 4650, 5000, 5200, 5400, 5600, 5800, 6000, 6200, 6400, 6600, 6800

Low proximity, large separation: 600, 700, 900, 1100, 1300, 1500, 1700, 1900, 2250, 2450, 2800, 3000, 3200, 3400, 3900, 4250, 4600, 4950, 5150, 5500, 5700, 5900, 6100, 6300, 6500, 6700, 6900, 7100, 7300, 7500

Session two

High proximity, small separation: 800, 900, 1300, 1950, 2300, 2500, 2850, 3200, 3550, 3750, 4250, 4450, 4650, 5000, 5350, 5850, 6200, 6450, 6800, 7000, 7250, 7650, 7950, 8200, 8400, 8600, 8800, 9150

High proximity, large separation: 750, 1150, 1550, 1750, 2100, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250

Low proximity, small separation: 600, 700, 1300, 1800, 2150, 2300, 2500, 2700, 2900, 3400, 3600, 4400, 4600, 4950, 5150, 5350, 5550, 5900, 6100, 6300, 6650, 6850, 7050, 7400, 7600, 7800, 8150, 8350, 8550, 8750

Low proximity, large separation: 500, 750, 1150, 1350, 1550, 1750, 1950, 2150, 2500, 2700, 2900, 3100, 3300, 3500, 3700, 3900, 4100, 4300, 4500, 4700, 4900, 5100, 5450, 5650, 5850

Session three

High proximity, small separation: 750

High proximity, large separation: 450, 550, 750, 950, 1150, 1350, 1550, 1750, 1950, 2150, 2350, 2550, 2750, 2950, 3150, 3350, 3550, 3750, 3950, 4150, 4350, 4550, 4750, 4950, 5150, 5350, 5550, 5750, 5950, 6150

Low proximity, small separation: 750, 850, 1050, 1250, 1450, 1650, 1850, 2050, 2250, 2450, 2650, 2850, 3050, 3250, 3450, 3650, 3850, 4050, 4250, 4450, 4650, 4850, 5050, 5250, 5450, 5650, 5850, 6050, 6250, 6450, 6650

Low proximity, large separation: 550, 650, 800, 1000, 1200, 1400, 1600, 1800, 2150

Appendix D

Appendix D

Raw Data, Experiment Two

Table D-1: Generalization Response Rates

Subject	Part D	Part E	Part G	Part B
		Session one		
1	6	1	2	1
2	27	1	8	1
3	35	4	15	1
4	4	2	1	0
5	0	0	0	0
6	0	0	0	2
		Session two		
1	1	0	2	0
2	37	2	1	1
3	9	3	8	5
4	0	6	1	3
5	0	0	0	0
6	0	0	0	0
		Session three		
1	1	0	1	0
2	0	15	0	0
3	9	3	5	5
4	1	0	2	2
5	0	0	0	0
6	0	0	0	0

Table D-2: Response Latency and Distribution Data II

Latency is first value listed, all times are in milliseconds. Only responses to the first trial are listed.

Pigeon number 1

Session one

Part D: 400, 500, 700, 900, 1100
Part E: 1300
Part G: 6900, 7150
Part B: 8650

Session two

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Table D-2 (Cont'd).

Session three

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Pigeon number 2

Session one

Part D: 750, 800, 1000, 1200, 1550
Part E: No responses (>10,000)
Part G: 1100, 1200, 1300, 1500, 1600, 1800, 2000, 2200
Part B: No responses (>10,000)

Session two

Part D: 1700, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: 2950

Session three

Part D: 1100, 1100, 1300, 1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900, 3100
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Pigeon number 3

Session one

Part D: 400, 500, 700, 900, 1100, 1300, 1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900, 3100, 3300, 3500, 3700, 3900, 4100, 4300, 4500, 4700, 4900, 5100, 5300, 5500
Part E: 2200, 2450, 2650
Part G: 650, 900, 1000, 1200, 1400, 1600, 1800, 2150, 2350, 2700, 3050, 3250, 3450
Part B: No responses (>10,000)

Session two

Part D: 350, 450, 650, 850, 1100
Part E: 2050
Part G: 1000, 1050, 1250, 1450, 1800
Part B: 2350, 2400, 2600, 2800, 3000

Session three

Part D: 3350, 3400, 3600
Part E: 1100, 1300
Part G: 500, 750, 950
Part B: 6750

Table D-2 (Cont'd)

Pigeon number 4

Session one

Part D: 7650, 7800
Part E: No responses (>10,000)
Part G: 1700
Part B: No responses (>10,000)

Session two

Part D: No responses (>10,000)
Part E: 2150, 2350, 2700, 2900, 3100, 3300
Part G: No responses (>10,000)
Part B: 1550, 1650, 1850

Session three

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: 4400
Part B: 7750

Pigeon number 5

Session one

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Session two

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Session three

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Pigeon number 6

Session one

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Table D-2 (Cont'd).

Session two

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)

Session three

Part D: No responses (>10,000)
Part E: No responses (>10,000)
Part G: No responses (>10,000)
Part B: No responses (>10,000)